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Criteria for Municipal Solid Waste Landfills (40 CFR Part 258). Subtitle D of Resource Conservation and Recovery Act (RCRA) Design Criteria (Subpart D)

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In August 1988, the U.S. Environmental Protection Agency proposed Solid Waste Disposal Facilities Criteria (40 CFR Part 258) for municipal solid waste landfills. This background document provides the technical support for a portion of Subpart "D" - Design Criteria of Part 258.

This document contains a discussion of background information leading to the development of the categorical rule option and provides detailed information on the revised design criteria. This document discusses the general development of the design criteria while specifically addressing the following items: the various design options considered by the Agency, how the design standard was selected and alternatives considered, how location specific considerations are involved in the design standard, and what methodologies are available for meeting the design performance standard. Lastly, this document provides a discussion of landfill designs specifically addressing such items as liners leachate collection systems, and final covers.

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DESIGN CRITERIA
(SUBPART D)

"CRITERIA FOR MUNICIPAL SOLID WASTE LANDFILLS"
(40 CFR PART 258)

SUBTITLE D OF RESOURCE CONSERVATION AND RECOVERY ACT (RCRA)

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF SOLID WASTE

JULY 1988

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I. INTRODUCTION

The 1984 Hazardous and Solid Waste Amendments (HSWA) to the Resource Conservation and Recovery Act (RCRA) directed EPA to revise the "Criteria for Classification of Solid Waste Disposal Facilities and Practices" (40 CFR Part 257) for facilities that may receive household hazardous waste (HHW) or hazardous waste from small quantity generators (SQGs). Such revisions shall be those necessary to protect human health and the environment and may take into account the "practicable capability" of facilities to implement the Criteria. At a minimum, the revisions should require ground-water monitoring as necessary to detect contamination, establish location standards for new or existing facilities, and provide for corrective action as appropriate.

In carrying out this mandate, EPA has undertaken efforts to revise the current Criteria. EPA is initially limiting the Criteria revisions to municipal solid waste landfills (MSWLFs) because these are the only facilities for which the Agency has complete and reliable data, as discussed in the Revised Final Draft Report to Congress: Solid Waste Disposal in the United States, Volume I and II [EPA, April 1988]. The rationale for this choice is further discussed in the Background Document for Options Selection [EPA, Sept. 1986].

Section II of this document provides a discussion on the background information that supports the Criteria revisions and Section III provides detailed information on the development and evaluation of the design criteria for MSWLFs. Additional background documents have been developed to support other aspects of the revised Criteria.

II. BACKGROUND

This section provides the legislative and regulatory background for understanding the current status of the Subtitle D program. Beginning with the legislation establishing Subtitle D of the Resource Conservation and Recovery Act of 1976, this section briefly reviews Federal and State implementation efforts from 1978 up to 1981 when Federal attention turned to the hazardous waste program and Federal funding to State Subtitle D programs ended. This section then outlines the new Subtitle D provisions contained in the Hazardous and Solid Waste Amendments of 1984 and describes EPA's major activities implementing these provisions.

A. SUBTITLE D OF THE RESOURCE CONSERVATION AND RECOVERY ACT

With the passage of the Resource Conservation and Recovery Act (RCRA) of 1976, Congress significantly expanded the Federal role in controlling the management of waste materials in the United States. Subtitle C of RCRA required EPA to establish a comprehensive regulatory program to ensure proper management of hazardous waste. Subtitle D required EPA to provide technical assistance to the States and to develop Federal criteria for controlling solid waste management practices, and authorized Federal financial assistance to help the States accomplish this effort.

Subtitle D of RCRA established a cooperative framework for involving Federal, State and local governments in dealing with solid waste problems. The Federal role in this arrangement is to provide technical assistance to States and regions for planning and developing environmentally sound waste management practices and to furnish financial assistance to enable States to implement these measures. The actual planning and implementation of solid waste programs under Subtitle D, however, remain State and local functions. The primary provisions of Subtitle D, that are discussed later in this section, include:

- Section 4002 -- Federal Guidelines for State Plans.
- Section 4004 -- Criteria for Solid Waste Disposal Facilities.
- Section 4005 -- Prohibition of Open Dumps.

In addition to these technical provisions, Section 4008 of Subtitle D authorizes EPA to provide grants to States for development and implementation of solid waste management plans, resource recovery programs, and resource conservation programs.

B. IMPLEMENTATION OF SUBTITLE D

In a series of rulemaking beginning in 1978, EPA began the process of implementing the provisions of Subtitle D. The Section 4002 guidelines for State plans were completed in 1979, and EPA began reviewing plans submitted by States and providing grants to States for program planning and implementation. The Criteria for classifying solid waste disposal facilities also were finalized in 1979. These Criteria were used by the States to classify facilities as either "sanitary landfills" or "open dumps". EPA published the first inventory of open dumps in 1981. In that year, however, Federal funding for State nonhazardous waste programs that implemented and enforced the Criteria was terminated.

Guidelines for State Solid Waste Management Plans

Pursuant to RCRA Section 4002(b), EPA promulgated guidelines for the development and implementation of solid waste management plans on July 31, 1979 (44 FR 45066). These guidelines identify the minimum statutory requirements that State plans must address and also deal with a full range of solid waste management, materials conservation, and resource recovery issues.

As the centerpiece of the Subtitle D program, the State solid waste management plan serves a critical function. It is through this plan that each State identifies a general strategy for protecting public health and the environment from adverse effects associated with solid waste disposal, specifies efforts for encouraging resource recovery and resource conservation, and formulates plans for providing adequate disposal capacity within the State. The plan also describes the institutional arrangements that the State will use to implement its solid waste management program.

Under Subtitle D, EPA reviews and approves State plans that meet the Agency guidelines. As of June 1988, EPA has fully approved 25 States' solid waste management plans and partially approved another six. EPA also had authority to provide grants to States to assist them in development and implementation of their plans. However, EPA discontinued those solid waste grants in 1981 when the focus of the Federal program turned to hazardous waste.

Federal Criteria for Solid Waste Disposal Facilities

Pursuant to RCRA Sections 4004(a) and 1008(a)(3), EPA proposed Criteria for classifying solid waste disposal facilities on February 6, 1978 (43 FR 4942). Final Criteria were promulgated on September 13, 1979, and minor modifications were issued in September 1981. These Criteria are entitled the "Criteria for the Classification of Solid Waste Disposal Facilities and Practices", and are found at 40 CFR Part 257. They provide minimum national standards for any solid waste disposal facility or practice, including landfills, surface impoundments, land application units, and waste piles. The Criteria include general environmental performance standards that establish the level of protection necessary to ensure that "no reasonable probability of adverse effects on health or the environment" will result from operation of the facility. A facility that meets these Criteria is classified as a "sanitary landfill"; a facility in violation is classified as an "open dump" and must be upgraded or closed.

Implementation and enforcement of these Subtitle D Criteria are the responsibility of State and local governments. In addition, private citizens may use RCRA's citizen suit provisions to bring actions in Federal court to enforce the Criteria against violators.

C. SUBTITLE D PROVISIONS OF HAZARDOUS AND SOLID WASTE AMENDMENTS OF 1984

On November 8, 1984, the Hazardous and Solid Waste Amendments of 1984 (HSWA) were passed. These amendments affected virtually every part of the RCRA program, including solid waste management.

Section 302 of these Amendments directed EPA to study and revise the Criteria, as well as examine the need for additional enforcement authorities. This Section states that EPA must "conduct a study of the extent to which the (Criteria)...applicable to solid waste management and disposal facilities, including, but not limited to landfills and surface impoundments, are adequate to protect human health and the environment from ground water contamination." This study, which must be completed and delivered to Congress in report form, "shall also include recommendations with respect to any additional enforcement authorities which the administrator, in consultation with the attorney general, deems necessary" to protect ground water.

In addition to the study, Section 302 of HSWA requires EPA to promulgate revised Subtitle D Criteria for facilities that receive hazardous household waste or hazardous waste from small quantity generators. HSWA states that such revisions "shall be those necessary to protect human health and the environment and may take into account the practicable capability of...facilities [to implement the Criteria]. At a minimum, [the] revisions...should require ground- water monitoring as necessary to detect contamination, establish criteria for the acceptable location of new or existing facilities, and provide for corrective action as appropriate."

HSWA also requires each State to establish by November 8, 1987, a permit program or other system of prior approval for facilities receiving small amounts of hazardous waste. This permit program is meant to ensure that such facilities are in compliance with the Criteria. Within 18 months of EPA's promulgation of the revised Criteria, each State must modify its permit program or alternate system accordingly. If a State fails to develop and implement an appropriate permit program, or other system of prior approval, EPA is given the authority to enforce the Criteria at facilities accepting household hazardous waste or small quantity generator waste.

D. SUBTITLE D STUDY AND CRITERIA REVISIONS

EPA is currently proceeding with implementation of HSWA's Subtitle D requirements, including the completion of the Subtitle D study and the development of the Criteria revisions. The major objectives of the Subtitle D study are to identify, characterize, and evaluate the environmental and human health impact of all solid waste disposal facilities and to determine the adequacy of the current regulatory program and Subtitle D enforcement authorities. The Subtitle D study was conducted in two phases. During Phase I of the study that was completed in October 1986, EPA used existing information gathered from the literature, States, EPA files, voluntary submissions from facility owners or operators, and any other available sources to address the objectives of the study.

In Phase II, which is still proceeding, EPA will concentrate on filling the information gaps identified during Phase I through collection of additional existing data and original data collection efforts. Phase II will result in the completion of the Subtitle D study report and its submission to Congress.

At the same time, EPA is developing changes to the Subtitle D Criteria for facilities that receive household hazardous waste and small quantity generator hazardous waste. This document provides detailed background data and information that was used to develop and evaluate the general facility design criteria for new and existing municipal solid waste landfills.

III. DEVELOPMENT OF DESIGN CRITERIA

This Section provides discussion and background information that supports the development of the design criteria for municipal solid waste landfills (MSWLFs). The objective of the design criteria and methods by which the Agency believes these criteria may be met are explained and discussed in detail.

A. OBJECTIVES

EPA's concern with the design of MSWLFs centers on the potential for contaminants to migrate from the facility. Contaminant migration occurs when precipitation and other liquids percolate through the solid waste in the landfill, forming a leachate composed of the soluble constituents in the waste. Different hydrogeologic conditions influence both the rate at which leachate is generated and the potential for leachate to escape from the facility and eventually reach the ground water.

EPA's objective is to develop design criteria that provide adequate protection to human health and the environment and allow for the consideration of the varied climatic and hydrogeologic conditions found across the country. The design criteria should also allow the States to consider site-specific characteristics when implementing the criteria and should not result in undue disruption of existing State programs. Further, the criteria must be enforceable at the Federal level and through citizen suits and should take into account the practicable capability of the regulated community.

B. DISCUSSION OF OPTIONS

In developing a rule that meets the objectives discussed above, EPA has considered several alternative approaches. These approaches are:

- Uniform design criteria
- Categorical design criteria based on location, and
- Performance criteria

Each of these approaches and their pros and cons are presented in the following sections.

1. Uniform Design Criteria

A uniform design standard would impose specific design requirements for all MSWLFs regardless of location. This approach assumes that most facility locations are "poor" and imposes comprehensive design standards strict enough to protect human health and the environment in such locations.

This approach provides the most protection to human health and the environment and is easy to implement and enforce because the standards are explicitly stated. However, such an approach would severely limit a State's ability to consider site-specific characteristics and would result in the disruption of many existing State programs. Because this approach does not consider site-specific factors, it may result in over-regulation of facilities in "good" locations by requiring unnecessary controls. In addition, this approach does not take into account the practicable capability of the regulated community. This approach, therefore, was not selected.

In order to account for site-specific characteristics, the Agency also considered the uniform design standards approach with variances. Under this approach, variances would be granted if the owner or operator could demonstrate that equivalent protection would be provided by site-specific location characteristics and an alternative design. This approach parallels the one adopted for hazardous waste facilities under Subtitle C of RCRA, that calls for appropriate technology for landfill design and imposes virtually identical requirements (e.g., double liners and leachate collection systems) at all new hazardous waste landfills. Variances are allowed based on an adequate demonstration by the owner or operator. This approach may result in implementation difficulties because of public pressure that may limit State or local flexibility in granting variances even though they may be warranted. This option provides a high assurance of protection of human health and the environment, but may over-regulate some facilities by requiring unnecessary controls. In addition, this approach does not take into account the practicable capability of the waste management industry because obtaining a variance would be costly and difficult. For these reasons this approach was also rejected.

2. Categorical Approach

The second approach considered was to impose categorical requirements. The concept behind this approach is to categorize all locations on the basis of certain site-specific characteristics (e.g., climate, geology), then set individual requirements for each category. Under this approach, appropriate requirements can be matched to specific categories of locations. Methods of establishing location categories and their corresponding requirements would be specified in the revised Criteria, then States, using information submitted by the owner or operator, could determine the category and apply the associated requirements to a given facility. A key advantage to the categorical rule approach is that it establishes a uniform process for effectively matching requirements to potential problems. For example, areas of the country characterized by abundant rainfall could require provisions for the collection of generated leachate. Conversely, the more arid areas of the country do not necessarily generate leachate in quantities sufficient to warrant leachate control systems.

This categorical requirements approach would be easy for the States to implement and provides protection without over-regulation. However, to address every locational consideration and to match appropriate requirements, a complex, sophisticated scheme may be necessary. This complex scheme would be difficult to develop. In addition, this approach would restrict State flexibility in making decisions because it specifies which designs are necessary for each location. Because of the difficulties in developing such an approach and the limited flexibility, the approach was not selected as the basis for developing the design criteria. However, this approach does have merit, and is discussed later in this document in the context of the approach selected.

3. Performance Criteria

The third approach is to establish a performance standard based on risk-based health limits. A performance standard based on health-risk levels provides adequate protection to human health and the environment. These limits establish acceptable concentration levels for various constituents based on human-health effects. This allows the owner or operator to take into account site-specific conditions when designing the facility to ensure that the concentration of contaminants, at a specified compliance point, are below the health limits.

A performance standard allows State solid waste management programs to make the final decision as to how the standard will be achieved based on site-specific characteristics. Many States have standards that incorporate either overall performance standards for design and operation of MSWLFs or standards for the performance of various components of the landfill, such as liners or leachate collection systems. Therefore, EPA believes that this approach would result in minimal disruption to State programs. A discussion of State programs is provided in the background document entitled Updated Review of Selected Provisions of State Solid Waste Regulations, [EPA, July 1988a].

A performance standard as opposed to a strict design standard, also allows for the consideration of innovative technologies that may be developed in the future that are capable of meeting the health limits. In addition, the Agency believes that because of the varied hydrogeologic and climatic conditions found across the nation, it would be difficult to develop strict design standards that would be appropriate for all locations. Further, by not imposing strict design standards that may not be necessary in a given location, the Agency is not over-regulating the regulated community. This approach, therefore was selected and is discussed further in the following Section.

C. DISCUSSION OF STANDARD SELECTED

1. Standard Selected

EPA has selected a performance standard for new MSWLF units that will require owners and operators to design such units to meet a specific design goal linked to a health- and environmental-based ground-water risk level, at the waste management unit boundary, or at an alternative boundary specified by the State. The design goal is an overall ground-water risk level that must be established, by the State within the 10^{-4} to 10^{-7} protective risk range.* The risk range is consistent with the requirements for determining the ground-water trigger levels and the ground-water protection standard (GWPS). However, the trigger levels and GWPS are defined in the ground-water monitoring section of the rule and are discussed in the background document entitled, Ground-Water Monitoring and Corrective Action (Subpart E).

However, unlike the trigger levels and the GWPS, the design goal represents the overall ground-water risk level (i.e., the combined risk from all constituents) that the State believes is necessary to protect human health and the environment. The design features the owner or operator must consider to meet this standard include liner systems, leachate collection systems, and final cover systems. The alternative boundary, that may be approved by a State, shall not exceed 150 meters from the waste management unit boundary and shall be located on land owned by the owner or operator of the MSWLF.

A different performance standard has been selected for existing MSWLF units. This standard requires owners and operators to install final cover systems upon closure that prevent the infiltration of water through the cover and into the waste. This different standard for existing units, that does not require existing units to meet a health- or environmental-based design goal, was selected because of practical and environmental problems associated with retrofitting of such systems. The Agency believes that existing MSWLFs have not been purposely designed with liners and leachate collection systems to specifically meet such a design goal. Many existing facilities, although they may have been equipped with some type of liner or leachate collection system, may already have contaminated ground water to some extent [EPA, July 1988b]. For existing facilities to meet the same design performance standard as new facilities, retrofitting may be necessary. Such retrofitting may be impractical, may result in additional environmental problems from the removal and temporary storage of wastes from many landfills, and may be beyond the practicable capability of the regulated community. On the other hand, owners or operators of new MSWLFs units can design their facilities with liners and leachate collection systems designed to meet the design goal without the same implementation problems as discussed above.

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* EPA is considering alternatives to the 1×10^{-4} to 1×10^{-7} risk range. The Agency specifically requests comment on a fixed risk level of 1×10^{-5} or an upper bound risk level of 1×10^{-4} (with the States having discretion to be more stringent) as alternatives to the proposed risk range. A fixed risk level of 1×10^{-5} would provide a uniform level of protection across all States. On the other hand, setting an upper bound risk level of 1×10^{-4} would allow States greater flexibility in establishing more stringent risk levels based on site specific conditions.

2. Alternatives Considered

EPA considered three alternatives to the selected performance standard. These alternatives were: (1) require MSWLFs to be designed to meet the design goal at the unit boundary but make no allowance for an alternative boundary, (2) require MSWLFs to be designed to meet the design goal at the unit boundary or an alternative boundary specified by the State (current standard in 40 CFR Part 257), and (3) require MSWLFs to be designed to meet the design goal at boundaries established by the State based on the resource value of the ground water, as defined by EPA's Ground-Water Protection Strategy, within the property boundary or a Federally mandated distance cap. These alternatives were evaluated based on the following: the potential extent of ground-water contamination that may result, State flexibility, ability to enforce the standard at the Federal level or through citizen suits, and the overall practicality and cost to the regulated community.

The first alternative, requiring MSWLFs to be designed to meet the design goal at the unit boundary provided the most protection for human health and the environment because, by strictly defining the point of compliance as the unit boundary with no alternative, it limited the areal extent of ground-water contamination. For the same reason, this alternative could be easily enforced at the Federal level or through citizen suits. However, it limited State flexibility by not allowing States to consider site-specific conditions when determining a point of compliance. Further, by not allowing site-specific conditions to be considered, this alternative could result in overregulation and increased cost to the regulated community.

The second alternative, requiring MSWLFs to be designed to meet the design goal at the unit boundary or a State selected alternative, provided more flexibility to the States by allowing State determined alternative boundaries. It was also less burdensome to the regulated community because site-specific factors could be considered thereby avoiding overregulation and increased costs. However, it is considered less protective of human health and the environment because there is a potential for a greater areal extent of ground water to be contaminated than the first alternative. This alternative also could be difficult to enforce at the Federal level or through citizen suits because the alternative boundary is not strictly defined.

The third alternative, requiring MSWLFs to be designed to meet the design goal at boundaries established by the State based on resource value of the ground water, within the property boundary or a Federally mandated distance cap, is more protective of human health and the environment than the second alternative because it ensures that ground water is adequately protected based on its resource value and because the distance cap ensures that large areas of ground water will not be contaminated. Because the alternative boundary is clearly defined, this alternative is also easily enforced at the Federal level or through citizen suits. It also considers site-specific factors reducing the possibility of overregulation and increased costs to the regulated community. However, this alternative severely limits State flexibility by defining resource value at the Federal level. EPA believes that decisions concerning the value of ground-water resource are best left to the States.

The Agency believes that the standard selected provides a balance of the positive aspects of the above alternatives. It limits the potential areal extent of ground-water contamination by placing a distance cap on the alternative boundary. In addition, it allows State flexibility in setting the alternative boundary by not defining resource value at the Federal level. Because it allows site-specific factors to be considered, it reduces the potential for overregulation and increased costs to the regulated community. Finally, it is enforceable at the Federal level or through citizen suits because it defines limits on the point of compliance for MSWLFs.

D. LOCATION SPECIFIC CONSIDERATIONS

The selected standard requires that new MSWLF units be designed to meet a specified design goal at the waste management unit boundary (or alternative boundary). To meet this standard the owner or operator must consider various site-specific factors in selecting the controls necessary. These factors include at a minimum: (1) the climatic factors of the area; (2) the hydrogeological characteristics of the facility and surrounding land; (3) the volume and physical characteristics of the leachate; (4) proximity of ground-water users; and (5) ground-water quality.

Each of these factors are discussed below.

1. Climatic Factors

Leachate is formed when precipitation and any other liquids percolate through the landfill, causing soluble components to enter into solution and become mobile. Different climatic settings influence both the amount and rate at which leachate is generated. Factors affecting the availability of water to generate leachate include direct precipitation, surface run on, ground-water intrusion, codisposal of liquid wastes, and refuse decomposition [Lu et al., 1985]. Water reaching the landfill surface by precipitation or surface run on may either evaporate or transpire, infiltrate through the final cover, percolate into the waste, or leave the site as surface runoff. The impact of these factors on generating leachate is typically determined from a water balance calculation [Lu et al., 1985]:

$$L = P - ET - R/O$$

where:

L = annual leachate generation
P = annual precipitation
ET = evapotranspiration (either potential or actual)
R/O = annual surface runoff

In most cases, precipitation is the primary climatic factor that controls leachate generation at landfills, provided that ground water intrusion and liquid waste codisposal is minimal [Lu et al., 1985]. Precipitation includes rainfall and snowfall. The amount of precipitation is expressed as the amount of water (in inches or millimeters) that would accumulate on a sealed, level surface. Existing precipitation records from the National Weather Service, the National Oceanographic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS) Water Atlases can be used to determine annual rainfall for a particular area. Precipitation measurements from these sources usually cover a sufficient period of time to be representative of mean annual precipitation.

Evapotranspiration can be expressed as either potential evapotranspiration (PET) or actual evapotranspiration (AET). Potential evapotranspiration (PET) represents the amount of water that could evaporate from soil surfaces and transpire through plants when adequate soil moisture supply is available at all times. Temperature, relative humidity, and wind speed are among the primary factors that influence PET for a particular type of vegetation. A number of empirical equations have been developed to estimate PET because its measurement is experimentally difficult (see Lu et al., for various PET equations). The Thornthwaite method is one such empirical approach that has been used by climatologists, geologists, agricultural engineers, and sanitary engineers. The procedures and supporting information for the method are well developed [Fenn et al., 1975]. The Thornthwaite equation is based on an exponential relationship between monthly temperature and mean monthly water consumption. Several tables have been developed for calculation of evapotranspiration rates [Lu et al., 1985]. Pan evaporation, the amount of water that potentially can evaporate from a fresh water surface, is sometimes used as a proxy for PET. This factor often is considered similar to lake evaporation and is not representative of landfill conditions. Because adequate moisture is not always available, PET generally overestimates the amount of moisture that plants can transpire. Plants actually transpire less water as soil moisture content decreases [Fenn et al., 1975]. Actual evapotranspiration (AET) is derived from PET by making adjustments for the decrease in soil moisture that is available for plants. During the active life of the MSWLF, little vegetation is usually present at the working areas of the landfill. Therefore, PET or AET will overestimate the amount of moisture that may be returned to the atmosphere via this method.

Runoff, although not a climatic factor, normally is expressed as the amount of water that will leave the site in the form of overland flow. Major land surface conditions affecting runoff include topography, cover material, vegetation, soil permeability, antecedent soil moisture, and artificial drainage. Surface runoff on or adjacent to a landfill site can be determined by surface measurement, empirical formulas, or graphic methods. Details on each of these methods can be found in Lu et al., (1985). During the life of the landfill, little runoff is expected to occur from the active portion of the landfill because: (1) precipitation that falls onto the active unit will readily infiltrate into the waste, and (2) the irregular surfaces caused by construction activities at most active landfills prior to closure do not necessarily promote runoff. In addition, the variety and irregularity of conditions at landfills make it difficult to accurately measure or calculate runoff from the unit.

Climatic conditions impact leachate generation differently depending on the stage of landfill construction. As discussed above, evapotranspiration and runoff play relatively minor roles during the active life of a unit and therefore, precipitation is the key climatic element during this period. After closure, evapotranspiration and runoff along with precipitation play a role in leachate generation. Later Sections of this report discuss these factors and how they can be used to determine final cover design.

2. Geologic Factors

Saturated Flow

The nature and extent of the geologic material underlying a MSWLF controls the fate and transport of leachate generated by the facility. In the simplest case, a contaminant contained in the leachate will travel at the same velocity of water as it moves downward to and through the aquifer. The analysis of water flow through geologic material is generally based on Darcy's Law, which is based on a linear relationship between the rate of flow and the driving forces. For one dimensional, steady-state flow through homogeneous material, the common form of Darcy's equation is given as [Freeze and Cherry, 1979]:

$$Q = -KiA$$

where

Q = flux rate (length^3/time (L^3/T))
K = hydraulic conductivity (L/T)
i = hydraulic gradient (dimensionless)
A = cross-sectional area (L^2)

Darcy's equation can be rearranged to determine the velocity of flow through soil and other porous geologic material by accounting for the porosity of the material:

$$V = \frac{Q}{nA} = \frac{-Ki}{n}$$

where V = average linear velocity (L/T)
n = porosity (dimensionless)

The porosity term accounts for the fact that flow passes through only that portion of the cross-sectional area that is occupied by void space. In general, rocks have lower porosities than soils; gravels, sands, and silts have lower porosities than soils rich in platy clay materials; and poorly sorted deposits have lower porosities than well sorted deposits. Attachment 1 in Appendix A provides porosity values for a range of geologic materials. In fractured rocks, void space also consists of secondary porosity, that may be due to secondary solution or structurally controlled regional fracturing. Secondary porosity may be related to primary porosity based on the aperture of the fractures and joints, and their density. Both primary and secondary porosity should be considered when calculating the average linear velocity of flow.

Hydraulic gradient, the driving force in Darcy's equation, is the change in hydraulic head per unit distance along the ground-water flow path. For example, if the hydraulic head decreases by 1 m over a flow length of 100 m, the hydraulic gradient is equal to 0.01 m/m. In ground-water flow, hydraulic head involves two components: elevation head and pressure head. The elevation head is the distance from a reference datum point, usually sea level, to the point of measurement. Pressure head is equivalent to the depth of water above the point of measurement. These components of hydraulic head are shown schematically in Attachment 2 of Appendix A.

Hydraulic gradients can range from greater than 1.0 near a point of ground-water recharge, to less than 0.0001, a value associated with extensive areas of flat terrain [EPA, 530-SW-86-022B, 1986]. Under most conditions of unconfined ground-water flow, the hydraulic gradient is much less than 1.0. Factors influencing hydraulic gradients include: 1) aquifer characteristics, 2) conditions at the boundaries of the flow system (i.e., river elevation, ground-water discharge from underlying bedrock into a sand and gravel aquifer, etc.), and 3) system inputs and outputs (i.e., precipitation, evapotranspiration, etc.). System inputs and outputs may also include man-induced aquifer stresses such as ground-water discharge or recharge at a well, or seepage from an impoundment facility.

Depending on the specific location, the geologic material below a MSWLF may be saturated or unsaturated. Darcy's Law is valid for both saturated and unsaturated flow; however, an important difference between saturated and unsaturated flow is the value for hydraulic conductivity. The saturated hydraulic conductivity of a given material is essentially constant, being dependent on the size and configuration of the soil pores. Particle size distribution and soil structure are the properties that saturated hydraulic conductivity is most directly related [Hillel, 1971]. Coarse textured sands and gravels generally have higher saturated conductivities than fine textured silts and clays. Similarly, soils with stable granular structure conduct water much more rapidly than do those with unstable structure that break down upon being wetted. Attachment 3 in Appendix A indicates the range of values for saturated hydraulic conductivity for a wide variety of geologic materials.

Unsaturated Flow

When soils are saturated, all of the pores are filled with water so that hydraulic conductivity is maximal. When the soil becomes unsaturated, some of the pores become air-filled and the conductive portion of the soil's cross-sectional area decreases correspondingly. For this reason, the transition from saturation to unsaturation generally entails a steep drop in hydraulic conductivity, that may decrease by several orders of magnitude from its value at saturation [Hillel, 1971]. An example of the dependence of hydraulic conductivity on moisture content is shown in Attachment 4 (Appendix A) for a sand and loam soil.

Unsaturated flow is governed by the same general principles affecting saturated flow; that is, its direction and rate are related to the hydraulic conductivity and to a driving force. In this case, the driving force is primarily two forces, the gravitational potential and the matric potential [Marshall and Holmes, 1979]. The gravitational potential of soil water at each point is determined by the elevation of the point relative to some arbitrary reference level. The matric (or capillary) potential is a negative pressure potential resulting from the surface-tension forces of the soil matrix. The matric potential is an important factor in unsaturated flow, particularly in dry soils. For a given soil, the relationship between soil moisture content and matric potential is described by the soil moisture characteristic curve. Characteristic curves for two soils of different texture are shown in Attachment 5 in Appendix A. If two soils of different texture (or structure) are in contact with each other, at equilibrium they will attain equal potential but generally exhibit a discontinuity in water content, corresponding to their different moisture characteristic curves [Hillel, 1971]. This concept is important in field situations where textural stratification exists. For water to move from a fine-textured soil (clay) to an initially dry coarse-textured soil (sand), the fine-textured soil must be nearly saturated. Thus, knowledge of the soil moisture characteristic curve for each soil material and its relationship to hydraulic conductivity is needed to calculate water flow through unsaturated stratified soils.

The soil moisture characteristic curves can be determined relatively easily from laboratory experiments, however, methods for direct determination of hydraulic conductivity as a function of moisture content or matric potential over the unsaturated range of interest are experimentally difficult. As a result, various empirical equations have been developed to estimate the hydraulic conductivity of unsaturated soils [Clapp and Hornberger, 1978]. Several methods to calculate time of travel in the unsaturated zone, based on empirical equations, are prescribed for determining vulnerable hydrogeology under Subtitle C Guidance Manual, [EPA, 530-SW-86-022B, 1986]. Example problems for calculating time of travel using these equations are provided in Appendix A as Attachment 6.

Contaminant Retardation

Contaminant migration through the overburden also is influenced by the chemical properties of the geologic material and of the specific contaminant. Processes that may occur as the leachate travels through the overburden include adsorption, precipitation, ion exchange, and complexation [Freeze and Cherry, 1979]. These interactions result in the distribution of the contaminant between the aqueous phase and the solid phase, thus reducing contaminant concentrations in the soil water. The net effect is retardation of the movement of the contaminant relative to the bulk water flow. In addition, some organic contaminants can be transformed into other compounds by complex chemical and biological mechanisms, including hydrolysis and oxidation.

CHEMICAL PRECIPITATION

Chemical precipitation reactions can control contaminant concentration levels and limit the total amount of contaminants in leachates moving through soil. The attenuation effect of precipitation is controlled by the solubility of the particular contaminant. When the soluble concentration of a contaminant in leachate is higher than that of the equilibrium state, precipitation occurs and the resulting contaminant level of the leachate is attenuated.

Precipitation reactions are most important in trace metal migration through soils [Lu et al., 1985]. In general, cadmium, copper, lead, nickel, and zinc can form carbonate precipitates in oxidizing leachate environments, and sulfide precipitates in reducing environments when carbonates or sulfates are present. The attenuation effect of precipitation of metals is more significant at neutral or higher pH values [Fuller, 1977]. At low pH levels, other mechanisms such as adsorption will usually dominate.

ADSORPTION

Adsorption is the most common mechanism generally associated with trace contaminant migration in soils [Lu et al., 1985]. Adsorption reactions are often in competition with precipitation reactions, with precipitation dominating at relatively high concentrations of contaminants. Under oxidizing or low pH conditions, adsorption can usually regulate the concentration of a contaminant below the level controlled by precipitation. Adsorption reactions occur at a relatively rapid rate when compared to precipitation reactions. Therefore, adsorption mechanisms may affect the concentration of a contaminant even if that contaminant has a low solubility.

ION EXCHANGE

Ion exchange in soil/water systems primarily originates from the exchange sites of layered silicate clays [Brady, 1974]. In general, these clays hold a permanent negative charge. Ion exchange arises from the need to balance this negative charge with positive ions to maintain neutrality. These ions are mobile and readily exchange with other cations in the soil solution. The total capacity of soils to exchange cations is called the cation exchange capacity (CEC). The four primary factors that affect the CEC of soils are: (1) kind of clay mineral present, (2) the quantity of clay mineral, (3) the amount of organic matter present, and (4) the pH of the soil [Fuller, 1977]. Major cations in landfill leachate (calcium, magnesium, potassium, and sodium) are usually present in higher concentrations than any of the trace metals [Lu et al., 1985]. Consequently, trace metals cannot successfully compete for the cation exchange sites that are dominated by the major cations. As a result, the removal of trace metals from leachate by cation exchange is usually insignificant when compared to other attenuation mechanisms [Lu et al., 1985].

COMPLEXATION

Complexation involves the reaction of metal ions with inorganic anions and organic ligands (chelation) to form complex inorganic ions and organometalic complexes [Stumm and Morgan, 1981]. Complex formation may effect attenuation and migration of contaminants in two ways. In the solution phase, complexation can increase the concentration of contaminants by the formation of soluble complex ions [Lu et al., 1985]. However, solution concentrations can be reduced if the complex formation occurs between a soluble contaminant and a solid surface such as organic chelates.

Metal complexes in soil have been categorized in terms of their solubility because this factor most influences their mobility. Three categories have been proposed [Keeney and Wilding, 1977]. These include: (1) relatively high molecular weight humic substances that have a high affinity for metals but are largely insoluble in soil, (2) low molecular weight organic acids and bases that demonstrate relatively high solubility in association with metals, and (3) soluble ligands that are precipitated on reaction with metals. The primary processes that retard the migration of organic contaminants are adsorption and degradation of the chemical [Mackey et al., 1985]. Adsorption of organic contaminants is affected primarily by two factors: solubility of the contaminant and the organic carbon content of the overburden. In general, organic compounds with low solubility exhibit greater retardation than high solubility compounds. The extent of adsorption is most often related to the organic carbon content of the soil by an adsorption coefficient (Koc). Many studies have shown that values of Koc for a specific chemical are relatively constant over a range of low concentrations, however, values of Koc for different organic chemicals range over seven orders of magnitude [Guswa and Lyman, 1983]. Consequently, extreme differences are apparent in the degree of adsorption for different organic chemicals.

HYDROLYSIS AND BIODEGRADATION

Organic contaminants can also be degraded or transformed into other compounds by chemical and biological mechanisms. Hydrolysis is the principle chemical reaction that can degrade organic contaminants in ground water. Hydrolysis involves a number of reactions with water in which carbon bonds are broken. However, most hydrolysis reactions are slow compared to biodegradation [Mackey et al., 1985]. Many factors affect the ability of microorganisms to degrade organic compounds, including pH, nature of the compound, the number and species of microorganisms present, availability of nutrients and oxidation status of the soil. Biodegradation is most prevalent in surface soils where the number and variety of microorganisms is greatest. The population density of soil microorganisms usually decreases rapidly with depth, resulting in slower rates of biodegradation.

3. Other Factors

The volume of leachate and its chemical and physical characteristics have a direct bearing on how it will interact with the underlying geologic material and, therefore, the concentration of the constituents that may eventually reach the waste management unit boundary. The ability of the geologic materials to attenuate the various leachate constituents is not only dependent on the properties of the geologic material, but also on the chemical and physical characteristics of each constituent in the leachate, such as the size of the molecule or ion, ionic strength, and the organic content of the constituent. Further, the attenuative capacity of a geologic material is not infinite. Therefore, large volumes of leachate or high concentrations of constituents may eventually overload the environment's ability to handle these materials.

Once leachate has reached the aquifer, various flow properties further affect the concentrations that eventually reach the waste management unit boundary. These properties include diffusion, dispersion, mixing and dilution, and the attenuative capacity of the aquifer material. For example, dispersion and subsequent dilution of a contaminant will reduce its concentration the farther from the point of release it migrates. Sorption of contaminants onto the aquifer material will further reduce its concentration with distance.

Proximity of ground-water users and existing ground-water quality are other factors when determining the necessary design features for a MSWLF unit. These factors are considered when establishing design goal for the unit. The design goal may vary for different locations based on these factors resulting in different levels of protection.

E. METHODOLOGIES FOR MEETING PERFORMANCE STANDARD

EPA has developed three methods for determining whether a MSWLF design will allow the unit to meet the performance criteria discussed earlier. These three methods are:

- an algorythm for determining risk,
- a categorical approach for matching design features with basic location features (i.e., hydrogeology and climate), and
- an empirical method using ground-water monitoring data from an existing adjacent unit.

Under the Risk-Based approach, an equation that considers the interaction of several key location factors in determining the potential risk posed by a facility is used to determine a risk score. If the calculated risk score exceeds the acceptable level (i.e., the design goal), the facility design and operating practices would need to be modified until an acceptable risk level is achieved. The effectiveness of the various design and operating practices in reducing the risk level would need to be estimated. Guidance on how these estimates would be determined could be supplied by either EPA or the State.

EPA has developed an algorythm to estimate the risk posed by a MSWLF unit which considers both location and design and operating practices. This algorythm was derived from data and observations from the Subtitle D Risk modeling efforts. The Subtitle D Risk Model (Model) builds directly on the Subtitle C Liner Location Risk and Cost Analysis Model [ICF, 1986], and has adopted many of its basic characteristics.

The risk-based approach is discussed in further detail in another background document specific to that subject. The other two methods, categorical approach and empirical method, are discussed in detail in the following sections.

1. Categorical Approach

Climate and geology strongly influence the potential for leachate to migrate from a landfill into the aquifer. Specifically, precipitation (P) and time of travel (T) in the overburden, between the bottom of the MSWLF and the top of the aquifer, are key measures of leachate migration. These two factors are used as the basis for establishing four location categories. The four categories are generally described as:

Category I - locations with "low" P and "long" T values;
Category II - locations with "high" P and "long" T values;
Category III - locations with "low" P and "short" T values; and
Category IV - locations with "high" P and "short" T values.

Each location category describes a climatic and hydrogeological setting with unique characteristics that affect landfill design. For example, Category I represents the best hydrogeologic setting for a landfill; it is a location with good climatic characteristics for a landfill (i.e., relatively arid) and good hydrogeology (i.e., good overburden characteristics indicated by "long" T values). Conversely, Category IV represents the worst locations (i.e., relatively humid climate, and "short" T values). Category IV locations would require specific landfill designs, such as liners and leachate collection systems, to compensate for the poor locational characteristics. Thus, the functional use of P and T is to identify the landfill design requirements for a particular location.

As shown in the summary report on the Subtitle D case studies [ICF, 1986] and the map representing precipitation presented in Attachment 7 of Appendix A, there is a great variability in the location settings across the nation. For example, as represented by the MSWLF case studies depths to ground water ranged from 0 to 480 ft, and depths to perched water 0 to 100 ft. The permeabilities of the native soils for these MSWLFs are from high permeable soils, including sands and gravels to low permeable soils, including silt and clay [ICF, 1986]. In addition, the annual mean precipitation across the nation ranges from 0 to 100 inches/year. The variability that exists from region to region and State to State results in various different settings for locating MSWLFs and each setting will be represented by one of the four location categories discussed above. The following discussion describes how "low/high" P and "short/long" T values are defined. These are referred to below as cut-off values.

Precipitation Cut-Off Value

When using the categorical approach, the Agency recommended that a "high/low" cut- off value of forty (40) inches per year be used for P. The value of P is determined by using historical records obtained from the National Oceanographic and Atmospheric Administration, and/or USGS water Altases. A "high" P is greater than forty inches and a "low" P is less than or equal to 40 inches. The cut-off value of forty inches is recommended because, based on an evaluation of MSWLF case studies in different climatic settings ranging from eight to 100 inches per year of precipitation, it appears that leachate accumulation is more likely to occur in areas that receive more than 40 inches of precipitation per year. Although the MSWLF case studies are not a true representative of the MSWLF universe and were not developed specifically for this analysis, they do represent MSWLF in various climatic settings and provide information that can be used to determine a precipitation cut-off value.

A total of 116 case studies were evaluated representing eight States. From these case studies, 31 were selected for this evaluation. The remaining case studies were not considered because (1) the waste was placed directly in the ground water, (2) the facility received or may have received liquid wastes or waste types that could not be identified, (3) the facility had not operated long enough to allow leachate time to accumulate, (4) the LCS was used to collect surface runoff in addition to leachate thus providing inaccurate results, (5) sufficient data were unavailable in the files to determine if leachate was generated, or (6) operating procedures (e.g., final cover) may have impacted leachate generation. In evaluating the thirty-one remaining case studies it is evident that four of the seven facilities in areas receiving less than 40 inches per year of precipitation are not accumulating leachate in amounts that problems were occurring. The facility files stated that only minimal amounts of leachate were being generated or ground-water monitoring indicated that leachate had not contaminated the ground-water. Almost half of the facilities that receive 40 and above inches per year showed significant amounts of leachate accumulation ranging from 7,280 gallons per year to 41.0 million gallons per year. The other half did not have data on the amounts of leachate generated, but ground-water contamination due to leachate had been documented. Specifically, five of these facilities had been ordered closed due to ground-water contamination.

Although there were three sites that receive approximately 30 inches of precipitation per year and collect leachate ranging in amounts from 0.25 million gallons per year to 2 million gallons per year, the Agency has decided to recommend 40 inches per year as the cut-off value because at least one facility that receives approximately 32 inches per year of precipitation showed no contamination problems associated with leachate accumulation. In addition, there were thirteen other facilities that receive less than 40 inches per year of precipitation that most likely do not generate leachate in amounts that necessitate collection, but were not included in the evaluation because the files did not specifically address leachate and a true determination could not be made. Additional information on this evaluation can be found in Attachment 8, Appendix A.

This is not to say that leachate will not be generated in areas with less than forty inches per year of precipitation, however, the evaluation indicates that leachate may not always be generated in amounts necessitating collection in the areas that receive less than 40 inches of precipitation. The Agency believes, however, that with the liquids restriction requirements (see Background Document on Operating Criteria - Subpart C) and other proper management measures (e.g., runon control), the unit in such areas may not reach field capacity prior to closure because of the moisture storage capacity of the waste [Lu et al., 1985]. Leachate, therefore, would not be generated in significant amounts prior to the installation of final cover that should be designed to minimize or prevent infiltration into the waste.

As discussed later in this Section, the Categorical Approach uses precipitation to determine whether a leachate collection system (LCS) is necessary. In "high" precipitation areas, a LCS will be necessary. However, as shown in the case studies reviewed there is some uncertainty as to whether leachate will be generated in "low" precipitation area in sufficient amounts to warrant collection. Therefore, under this approach, owners/operators of MSWLFs in such areas would need to demonstrate that leachate will not be generated in significant quantities. If demonstrated that leachate will not be generated in significant quantities then a LCS will not be necessary.

Time of Travel Cut-Off Value

The Agency is recommending that the time of travel cut-off value be based on the active life of the unit, where T is calculated as described later in this Section.

EPA considered the following options for the "short/long" cut-off value for T. The first option is to establish a single cut-off value (e.g., 20 years) based on an average unit active life. An average active life value is possible to derive from the various surveys the Agency has conducted, but may be difficult to justify because it either over- or under-regulates units whose active life does not match the derived value.

The second option is to establish a sliding cut-off value that is a function of the active life of the unit. This cut-off value would be a direct one-to-one ratio of T to active life (i.e., for a 20-year active life, the T cut-off value would be 20 years). This method provides greater flexibility than the first option and provides adequate protection to all locations based on the performance goal. However, it encourages development of short active life units to avoid the requirement that a liner be installed.

The Agency has selected a combination of the above two options where the T cut-off value is equal to the active life of the unit or 20 years, whichever is longer. A T value equal to or greater than this cut-off value is considered "long" and a T value less than this value is considered "short". The minimum value of 20 years for T was chosen because the average active life of a facility is approximately 30 years and a facility usually is comprised of more than one unit. Therefore, the Agency selected 20 years as the average life of the unit and as the minimum T value. EPA believes the use of this approach provides adequate protection for all sites and does not overregulate high-volume, short-term units. Once a unit is properly closed, the Agency believes that leachate generation will be significantly reduced by limiting infiltration into the landfill. The functional use of the T cut-off value is to determine which locations will require liners and the type of liner that may be required.

Methods to Determine Time of Travel

Four methods were considered that could be used to characterize the time of travel (T) for liquids migration through the overburden to the aquifer. The methods involve: (1) calculation of T based on a detailed time of travel analysis through the overburden (for saturated and unsaturated geologic material) using the approaches prescribed for determining vulnerable hydrogeology under Subtitle C guidance manual, [EPA, 530-SW-86-022B, 1986], (2) a wetting front approach for unsaturated soil only, (3) calculation of $T = D/K$ sat (based on the depth (D) and saturated hydraulic conductivity (K sat) of the overburden), and (4) calculation of $T = D/V$ (based on the average linear velocity of water flow through the overburden).

The detailed time of travel approach involves a rigorous analysis of water flow through the overburden. Complex analyses are required for flow through saturated or unsaturated materials, and depending on the complexity of the overburden, intensive field programs to collect data may be needed to perform the analyses. For saturated conditions, a flow net is constructed to represent the ground-water flow system. The flow path of least resistance is identified by inspection once a flow net is constructed for the site in question. The time of travel is then calculated for the flow path of least resistance.

To construct a flow net, several hydrogeologic parameters must be known, including:

- Vertical and horizontal head distribution,
- Vertical and horizontal hydraulic conductivity,
- Thickness of saturated layers, and
- Boundary conditions of the flow system.

The determination of vertical and horizontal head distribution requires the installation of piezometers. A piezometer is essentially an open pipe in which the elevation of a water level can be determined. The number of piezometers needed to characterize the system will depend on the complexity of the system. Extensive soil borings may be needed to adequately define the vertical and horizontal extent of stratigraphic layers to ensure the proper placement of the piezometers. In heterogenous materials, the piezometers must be spatially distributed and placed at varying depths to determine the existence and magnitude of vertical gradients. In addition, the thickness and hydraulic conductivity of each stratigraphic layer must be measured. Several laboratory and field methods can be used to determine the hydraulic conductivity of soils, including tracer tests, auger-hole tests, and pumping tests [EPA, SW-846, 1986; EPA, SW-925, 1984]. The thickness of a soil layer can be determined by evaluation of boring logs or by geophysical techniques. The boundary conditions of the area of interest must also be known to construct the flow net. The three general types of boundaries are: (1) impermeable boundaries, (2) constant-head boundaries, and (3) water table boundaries [Freeze and Cherry, 1979]. The boundary conditions are determined from a review of boring logs, geophysical reports, piezometer data and other hydrogeologic data for the site. Details on the construction of flow nets are provided in a number of hydrogeology textbooks and in the Subtitle C Guidance Manual for Determining Vulnerable Hydrogeology [EPA, 530-SW-86-022B, 1986].

Once the flow net is constructed, the flow path exhibiting the lowest gradient and highest velocity are selected to determine the time of travel. The velocity is calculated from Darcy's equation, described previously, and the time of travel is calculated by dividing the travel distance by the velocity of flow.

For unsaturated conditions, the detailed time of travel approach also requires extensive data inputs to calculate flow rates. Analytical or numerical solutions may be used to determine flow rates depending on the complexity of the problem. Analytical solutions are useful when the system is not complex or when simplifying assumptions are made. Numerical solutions are usually needed in complex layered systems in which the hydrologic soil properties are not constant with depth. Both types of solutions require, as a minimum, the following information:

- Stratigraphy of the site,

- Thickness of each soil or geologic unit,
- Relationship between moisture content and matric potential (characteristic curve) for each unit or soil, and

- Flux of water through the unsaturated zone.

The detailed time of travel analysis incorporates such specific information and can result in an accurate prediction of the time when leachate may reach the aquifer under a variety of conditions. However, this approach is data intensive and complex. The Agency believes that a less complex, conservative method of predicting leachate migration as discussed later, is adequate for establishing minimum design controls.

A second method considered by the Agency, for unsaturated soil only, is a wetting front approach. This method is based on equations developed for infiltration of water into dry soil and applies simplifying assumptions to calculate the time of travel. The equation used to calculate the time of travel is given as:

$$T = (L \Delta \theta)/q$$

where

T = time of travel (T)
L = length of the unsaturated zone (L)
$\Delta\theta$ = change in moisture content from behind the wetting front to dry soil ahead of the wetting front
q = infiltration rate (L/T)

The infiltration rate is approximated by using the net precipitation; and the length of the unsaturated zone is determined from boring logs and piezometer measurements. Moisture content behind and ahead of the wetting front can be determined from field measurements or estimated from emperical equations.

The principle assumption of this approach is that there exists a distinct and definable wetting front, and that behind the front the soil is uniformly wet and of constant conductivity. In many real situations, the wetting front is too diffuse to indicate its exact location [Hillel, 1971]. Furthermore, in texturally stratified soils there may appear to be several wetting fronts because coarse material and fine material will have different moisture contents under the same matric potential. Consequently, the wetting front approach is applicable for a limited range of conditions. In particular, the approach is useful when a constant water flux is applied to an initially dry soil. The approach may not be applicable for soils that are initially moist or that are uniform in moisture content under natural infiltration conditions. For example, the wetting front equation predicts decreasing time of travel as the change in moisture content behind and ahead of the front decreases. If the soil is initially moist, this approach would produce less conservative estimates for the time of travel, particularly if the soil moisture content is near saturation. Therefore, the Agency does not favor this approach, believing that conservative travel times may not be predicted for all unsaturated conditions encountered at MSWLF sites.

The third and fourth methods considered by the Agency are based on simple formulations of Darcy's Law:

$T = D/K_{sat}$, and

$$T = Dn_e/K\,sat = D/V$$

where: T = time of travel to aquifer
D = depth to aquifer
n_e = effective porosity
$Ksat$ = saturated hydraulic conductivity
V = average linear velocity

Both methods assume that flow occurs under saturated conditions and that the hydraulic gradient is equal to one. The third method is the most basic approach because data for only two parameters are needed: K sat and Depth. Depth to the aquifer may be obtained easily from a preliminary subsurface exploratory program, or during pre-screening, from boring and drilling logs from surrounding areas. Several laboratory and field methods are available to determine K sat as discussed previously. To screen various locations, literature values for K sat may be used for the time of travel calculation. Literature values must be verified by field tests to ensure that site-specific conditions match conditions predicted by the literature.

The method recommended for use under the categorical approach, however, is the D/V method for calculating time of travel because this approach requires minimal data, involves simple calculations, and approximates long-term conditions that could exist at a MSWLF. The D/V approach more accurately represents flow through porous geologic material than D/Ksat because the average linear velocity (V) incorporates effective porosity (n_e) in the calculation.

The average linear velocity (V) represents the velocity of which the bulk mass of ground water moves along a straight flow path. Average linear velocity accounts for the actual cross-sectional area through which flow occurs, and is defined as follows [Freeze and Cherry, 1979]:

$$V = Q/A{*}n$$

where: Q = volumetric flux (L^3/T)
A = cross-sectional area (L^2)
n = porosity (dimensionless)

The porosity of the geologic material must be accounted for by recognizing that water flows through only that portion of the material occupied by void space. The net effect of accounting for porosity in the flow calculation is to decrease the time of travel. Example time of travel calculations, based on D/K sat and D/V, are shown in Attachments 9 and 10 (Appendix A) to illustrate the effect of porosity on flow rates. For a silty clay (K sat = 1.0 ft/yr and n = 0.4), the time of travel through 100 feet of overburden would be approximately 97 years using the D/K sat method and 38 years using the D/V method.

The Agency recognizes that the simplifying assumptions made in the D/V method may not accurately reflect actual overburden conditions at all MSWLFs. As discussed in Section III.D, hydraulic conductivity values decrease several orders of magnitude from maximum values at saturation as the soil moisture content decreases. If the overburden is actually unsaturated, the assumption of saturated hydraulic conductivity values would generally result in calculated travel times that are less than actual travel times. As an example, Attachment 10 indicates that the saturated hydraulic conductivity for a loam soil is approximately 100 ft/yr (10^{-6}m/sec). At a moisture content of 0.3, the corresponding hydraulic conductivity would be approximately 1.0 ft/yr (10^{-8}m/sec). Thus, the time of travel through an unsaturated loam soil having a moisture content of 0.3 would be 100 times longer than the value calculated for saturated conditions assuming the same depth and unit hydraulic gradient under steady-state conditions.

The D/V method also assumes that the hydraulic gradient is equal to one, which means that the moisture content does not change with depth and that flow is vertically down under the influence of gravity. The implications of this assumption depend on whether the overburden is saturated or unsaturated. Hydraulic gradient is defined as the change in hydraulic head per unit distance in the direction of flow.

For saturated, unconfined flow (water table conditions), the hydraulic gradient is determined from the difference in elevation of the water table between two points, and includes both vertical and horizontal components. Under most saturated conditions, the horizontal component of flow is larger than the vertical component, therefore, typical gradients are much less than one. Consequently, the assumption of a unit hydraulic gradient will, in most cases of saturated overburden, result in calculated travel times that are less than actual travel times.

The hydraulic gradient in unsaturated soil has two primary components, suction gradient and gravity gradient. The suction component arises from the capillary forces of attraction that tend to draw water into a dry soil. The gravity component generally dominates the suction component under steady-state conditions in moist soils, such as the case when water is continually applied to a soil for several days. For such conditions, the unit hydraulic gradient is a reasonable assumption [EPA, 530-SW-86-022B, Appendix C, 1986]. When water is initially applied to a dry soil, however, the suction gradient is much larger than the gravitational gradient and water can move into the soil faster than when gravity is the only driving force. As the water, penetrates deeper, the average suction gradient decreases because the overall difference in hydraulic head divides itself over an increasing distance. This trend continues until eventually the suction gradient becomes negligible, leaving the unit gravity gradient as the only remaining force to move water downward [Hillel, 1971, p. 137]. Thus, the assumption of a unit hydraulic gradient is more appropriate for long-term, steady state conditions, rather than for short-term, transient conditions.

The Agency believes that a long-term approach is useful, but recognizes that more sophisticated methods may be desirable for some situations. For example, a number of computer models are available for simulating transport processes in saturated and unsaturated soil. More complex analytical techniques are also available [EPA, 530-SW-86-022B, 1986). Therefore, the other methods for calculating time of travel that are more accurate for regional conditions may be appropriate.

Liner Requirements

Under the categorical approach, the decision as to whether a liner is necessary will depend on the time of travel (T) of liquids through the overburden (from the bottom of the unit to the aquifer). Liners are necessary for units at which T is less than the active life of the unit or 20 years whichever is greater; for the purposes of this Section of the report this time period will be referred to as the "active life." The minimum of 20 years was chosen because preliminary data from Subtitle D survey indicates that the average active life of a facility is approximately 30 years. Because facilities normally include more than one unit, the Agency has selected 20 years to be representative of the average active life of a unit.

The liner/overburden combination should prevent migration of liquids to the aquifer during the "active life." In some locations the natural material in the overburden may be sufficient to meet this performance standard, however, in others, the natural overburden may need to be augmented by a liner. In either case, the liner/overburden combination should be capable of preventing migration of leachate to the aquifer during the "active life" of the unit.

Landfill locations that have overburdens already capable of satisfying this requirement would not require a liner. However, sites with high precipitation and "long" T may require a liner to enable the leachate collection system (LCS) to function properly. For example the site may have an adequate thickness of silty sand (overburden) to meet the T requirement. The permeability of this silty sand, however, is too high to allow the LCS (necessary because of high precipitation) to function properly. In this circumstance, modification to the base of the unit would be necessary (e.g., installation of a clay or synthetic liner).

At some landfill sites, the overburden materials will not be capable of satisfying the no migration during "active life" requirement. Various options exist to increase the capability of the overburden to retard liquid migration such as soil amendments and recompaction of existing materials. In such instances it may be necessary to install a natural or synthetic liner such that, in combination with the overburden, it increases the T to the necessary level (i.e., "active life").

Leachate Collection Requirements

In areas of low precipitation (or arid areas) little, if any, leachate is expected to be generated during the active life of the unit. Once a landfill is properly closed, the possibility of leachate generation is further reduced. The Agency believes, therefore, that LCSs may not be necessary at these locations. This is not to imply that leachate never will be generated at low precipitation locations. The waste itself already will have a certain amount of moisture in it when it is received at the facility and some will be generated as a result of waste decomposition. Further, an additional amount of infiltration from precipitation will occur during the active life of the unit during wet seasons. However, the wastes in a MSWLF have a certain capacity to absorb water. Moisture content at the time of placement is not a constant, but a function of waste composition, density, and climatic conditions. Fenn et al., [1975] found that the moisture content of wastes at the time of placement ranges from 10 to 20 percent. As shown in Table 1, refuse has a large capacity to absorb liquids before leachate is produced. Leachate production will not occur at rates equal to the precipitation in the area until waste saturation is exceeded, a condition significantly above field capacity [EPA, SW-870, 1983].

EPA recognizes that these and other factors will determine the rate and amount of leachate that will be generated at MSWLFs and that the installation of LCSs in low P areas may not always be necessary. However, the Agency recommends that a LCS be installed in low P areas unless the owner/operator can demonstate that the amount of leachate generated will not produce one foot of liquid at the bottom of the unit at any time during the active life of the unit. The one foot standard is recommended to reduce hydraulic head build-up in the unit.

The demonstration would require the owner/operator to project the contours of the facility at the end of each operating year. Based on these projections, a water balance would be performed for each operating year using the method developed by Fenn et al., [1975] to determine moisture routing through the waste. Each year, the amount of water that is available for percolation is routed from the intermediate soil cover into the uppermost waste layer. When a layer has reached field capacity, the excess liquid is routed into the next waste layer below. Any liquid that reaches the bottom of the unit is assumed to accumulate from year to year. If the depth of liquid is projected to accumulate more than 12 inches during the active life of the unit, then a LCS is required to remove the liquid. All areas of the unit that have not been properly closed must be included in this analysis. Once an area is properly closed, that portion of the unit is not included in future calculations. The above approach is further illustrated in examples provided in Attachment 11 in Appendix A.

Table 1

Moisture Content of Refuse[a]
(Average Values)

Refuse at	Percent by volume	Equivalent inches H_2O/ ft of refuse	Equivalent gallons H_2O/ yd^3 of refuse
Placement	10-20%	1.8"	30
Field capacity	20-35%	3.6"	60
Saturation[b]	--	6.6"	110

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[a] Source [EPA, SW-870, 1983]

[b] Based on a 0.4 porosity for refuse.

In areas of high precipitation, the climatic conditions are conducive to the continual generation of leachate. Leachate control, therefore, is believed necessary in order to prevent the build up of a hydraulic head within the facility. Again, once the facility is properly closed, leachate generation will be reduced to negligible amounts. However, leachate generated during the active life of the unit still will need to be collected for a period of time after closure, therefore, the LCS must be capable of functioning during the post-closure care period.

The Agency believes that LCSs are also necessary for facilities where the base of the unit is placed in a saturated zone. This is not to imply that units should be placed in aquifer media. However, certain types of geologic material such as clays may comprise the overburden and be saturated. Water from this saturated material eventually will seep into the waste, generating leachate if not controlled. A leachate control system, in such circumstances, will not only remove the leachate, it also may remove the water before it enters the waste. Installing separate collection systems for leachate and ground-water seepage may be desired to reduce unnecessary treatment costs.

Finally, EPA also recommends that units that install synthetic membrane liners (e.g., FML) should also install a LCS. Because of the low permeability of these liners, leachate will back-up, as discussed earlier, increasing hydraulic head that may damage the liner and establish conditions conducive to basement seepage. The installation of a LCS will remove leachate before these conditions occur.

2. Empirical Approach

A third approach for determining the landfill design characteristics necessary to comply with the design goal relies on the use of ground-water monitoring data from existing MSWLFs. Under this approach, an owner or operator planning lateral expansions of an existing facility or planning to build new units in similar locations to an existing unit could use ground-water monitoring results from existing units to determine if the new or expanded units need to employ designs that are more protective than the existing unit. If the concentration of constituents detected in the existing units' ground-water monitoring wells do not exceed the design goal (and leachate from the unit could be reasonably expected to have reached the monitoring wells), then the new or expanded unit would not have to apply a more elaborate containment design than the existing unit to comply with the design goal.

EPA believes that this approach is appropriate, in certain situations, for several reasons. First, many States have existing performance standards for MSWLFs similar to the ones being proposed by EPA. Such States, therefore, may have an historical record of the types of designs that are effective in meeting EPA's design goal in similar locations. Second, as the revised Criteria are implemented in the future, such an historical record of appropriate designs will evolve over time. EPA believes that, if the correlation between design, operation, and location indicates that the design goal will be met, it would be unnecessary to require owners and operators of MSWLFs in similar situations to conduct the extensive studies and demonstrations necessary to determine whether the unit will meet the design goal.

This approach requires that four conditions be met in order that its use may be successful. First, the new or expanded unit must have sufficiently similar location and waste characteristics to the existing unit so as not to pose greater threats to human health and the environment. Location characteristics that should be considered include:

- geology, including soil types, thickness of vadose and saturated zones, grain size, homogeneity of formations, moisture content, mineralogy and structure,
- hydrogeology, including hydraulic gradient, hydraulic conductivity, flow rates, and depth to ground water,
- ground-water use in the vicinity of unit,
- climate, including precipitation and evapotranspiration,
- surface topography, and
- land use.

Waste types to be accepted at the new or expanded unit must not be significantly different from those accepted at the existing unit. For units that only accept residential wastes, this may not pose a major problem. For units that accept small quantity generator wastes and/or industrial wastes, however, the owner or operator must demonstrate that there will not be any major differences in these wastes. For example, although two units may exhibit similar location characteristics (e.g., geology, climate), waste generation practices in the area of the new unit may be significantly different because of heavier industrialization. In such a situation, it may be difficult to demonstrate that waste types would not be significantly different between the two units.

Second, the existing unit must have a ground-water monitoring program that has been in operation over a long enough period of time to allow for leachate generation, release (accounting for the time required for failure of any liners), and migration to the monitoring wells. For example, water balance calculations may indicate that it will take five (5) years for the existing unit to reach saturation and begin generating leachate. The time necessary for the leachate to migrate through the liner (either calculated for natural liners as discussed elsewhere in this document or from manufacturer's specifications for FMLs) may be another five (5) years. Finally, calculations may indicate that it would take ten (10) years for the leachate to migrate from the bottom of the liner to the nearest monitoring well. The existing unit's monitoring program, therefore, would have had to be in-place for a minimum of twenty (20) years. This ensures that the monitoring data, discussed in the next paragraph, is representative of the effectiveness of the unit's design.

Third, the ground-water monitoring data must address all the constituents (i.e., the rule's Appendix II list) appropriate for determining the risk level that can be compacted to the design goal. Monitoring, therefore, must have included not only indicator parameters but also organic and inorganic constituents and should be compared to the "trigger levels" specified by the State pursuant to the ground-water monitoring requirements found in the revised Criteria. "Trigger levels" are discussed in more detail in the Background Document on the ground-water monitoring requirements. The constituents chosen should be those expected to be found in the landfill's leachate based on the wastes accepted at the landfill. If the monitoring data indicates that the design goal of the unit has been exceeded, then the design of the existing unit is not appropriate for the new or expanded unit.

If the design goal has not been exceeded, the owner or operator must meet the fourth condition of this approach. Monitoring data must be supplemented with appropriate modeling to predict the fate of hazardous constituents over a time period equivalent to the post-closure care period to determine if the design goal will be exceeded at any time by the existing unit. If the modeling demonstrates that the design goal of the existing unit will not be exceeded over this period of time, the existing unit's design is appropriate for the new or expanding unit.

F. LANDFILL DESIGNS

1. Liners

One of the most important factors, when considering protection of human health and the environment at MSWLFs, is leachate generation and subsequent migration to the aquifer. As precipitation enters a landfill, it infiltrates the wastes, dissolving and mobilizing contaminants and thereby creating leachate. Eventually a hydraulic head builds up at the base of the landfill and acts as a driving force for migration in the subsurface. The principal means of protecting the environment and human health at a MSWLF is to control the leachate and prevent it from escaping into the environment.

The purpose of lining a MSWLF is to prevent potentially polluting constituents of the disposed waste from seeping from the site and entering the aquifer. A liner is a hydraulic barrier that prevents or greatly restricts migration of liquids, thus facilitating their removal from the unit.

Based on the 1984 MSWLF facility survey it has been estimated that:

- 13% of the active landfills are equipped with liners (in-situ clay, recompacted clay, or synthetic membranes), and

- 56% of the planned landfills will be equipped with liners (in-situ clay, recompacted clay, or synthetic membranes).

Liners are already a widely accepted requirement for MSWLFs. Only 6 States do not require liners for MSWLFs through either a State regulation or guidelines. These States comprise only approximately 8% of all MSWLFs. Of the States requiring liners, 14 States require liners through State regulations and 28 States require liners through guidelines.

The MSWLFs case studies reviewed identified various types of liners currently being used, including compacted native and imported soils, compacted mixtures of native soils and bentonite, and synthetic membranes. The liner designs used varied somewhat from region to region.

In their performance, liners function by two mechanisms [EPA, SW-870, 1983]: (1) they impede the flow of leachates and thereby limit the movement into the subsoil and thence to the aquifer (therefore, requiring a liner material having low permeability), and (2) they adsorb or attenuate suspended or dissolved pollutants, whether organic or inorganic, thus retarding the migration of contaminants. This adsorptive or attenuative capability is dependent largely upon the chemical composition of the liner material and its mass.

Most liner materials function by both mechanisms but to different degrees depending on the type of liner material and the waste liquid and its constituents. For purposes of this report liners will be grouped into two major types:

1. Natural (soil or clay)
2. Synthetic (flexible membrane liners)

Membrane liners are the least permeable of the liner materials, but have little capacity to attenuate dissolved pollutants [EPA, SW-870, 1983]. Membrane liners are capable of absorbing and removing some organic material, however, due to their small mass, their attenuation capability is limited. Natural liners can have a large capacity to attenuate materials of different types, but they are considerably more permeable than the synthetic membranes. Soils of low permeability used as liner material are: (1) brought to a site or available on the site and (2) remolded and compacted to reduce permeability. Both types of liner materials (natural and synthetic) have the same general purpose--to prevent or limit leachate migration out of the MSWLF.

To meet the performance standard being established for MSWLFs, owners and operators may have to install a liner and/or modify the soils at the site based on specific location factors. Two of the methods EPA has suggested for determining whether the performance standard will be met (use of a risk-based algorithm or the categorical approach) consider the physical characteristics of the liner material, as discussed in this section, as well as the overburden (e.g., hydraulic conductivity).

Natural Liners

Natural liners consist of one or more layers of cohesive soil that have been compacted to achieve a low permeability. Natural liners are usually constructed of soils that contain appreciable amounts of clay. In some cases other materials, such as bentonite, are mixed with the soil when the soil does not contain sufficient clay [Goldman, 1985]. A natural liner may be overlain by one or more flexible membrane liners to increase the liner's ability to retard liquid movement. The Agency has developed a Technical Resource Document (TRD) [Goldman, 1985] that contains extensive data on design, construction and performance of clay lined waste management facilities. Although emphasis is given to hazardous waste facilities, the information presented in the TRD may be applicable to nonhazardous waste facilities.

Although recompacted clays may have low hydraulic conductivity, eventually liquids will seep through if a finite depth of liquid is maintained above the liner. A number of transit time prediction methods are available to determine the time it will take for liquids to seep through a liner. These methods range from simple, steady-state solutions of Darcy's Law, to complex numerical methods that describe transient flow and solute transport in saturated and unsaturated liners. Various transit time prediction methods and their applicability to various clay liner conditions are reviewed in the draft TRD [Goldman, 1985].

Numerical methods can be used to accurately describe the movement of the saturation front and solute transport in saturated and unsaturated clays. Computer programs are available to solve the generalized flow and solute transport problem in one or two dimensions. They generally require extensive data input regarding the variations of hydraulic conductivity and moisture potential with moisture content in clay and underlying site soils. Notable among the available programs to solve the unsaturated flow equation in a liner system is a finite difference program, "soil liner", developed by Goode and Smith [EPA, 530-SW-86-006, 1986]. This program was specifically written for a clay liner system and considers vertical, one-dimensional flow through the liner. The model requires values for saturated hydraulic conductivity and porosity for each element in the flow domain. In addition, functional relationships for each different type of material must be provided to determine the relative hydraulic conductivity, moisture content, and soil specific moisture capacity as a function of capillary suction potential. Similar input data will be required by all numerical methods that consider unsaturated flow.

The output from these numerical methods typically includes distribution of the variations of hydraulic conductivity and moisture potential with moisture content in clay and underlying site soils, moisture content, flow velocity, suction potential, and seepage flux at specified points in the flow domain. Numerical methods can provide accurate predictions of transit time through clay liners, however, the accuracy is dependent upon the quality of required data. In addition, numerical methods require expertise in the available models and hence may not be easily implemented.

A number of more simplistic analytical methods are available to estimate transit time [Goldman, 1985]. These methods make general assumptions concerning the flow processes through the liner to arrive at equations that are easy to calculate, but may sacrifice accuracy. The simple transit time equation proposed in Section III.E.1 for estimating travel time to the aquifer, as presented below, may also be used to estimate flow through a liner:

$$T = D/V$$

where: T = transit time through liner
D = thickness of liner
V = average linear velocity of flow

and:

V = Ksat/n

where: Ksat = saturated hydraulic conductivity
n = porosity

The key assumptions in this approach are:

- steady-state, saturated flow
- unit hydraulic gradient
- transport is by advection only; there is no diffusion or dispersion
- attentuation capacity of the clay is ignored.

Most clay liners are only partially saturated at the time of placement and become saturated due to the flow of leachate through them. Thus, unsteady state, unsaturated flow equations would be appropriate to describe moisture movement during the initial wetting stage. When unsaturated, the clay has lower hydraulic conductivity than when saturated (conductivity is a function of moisture content). However, suction forces induced by capillary tension in unsaturated soils may dominate over gravitational forces. During early stages of wetting of a compacted clay liner, capillary attraction forces will predominate over gravitational forces. As the clay liner becomes wetter, the capillary forces decrease in importance; and, when the liner is saturated, these forces become negligible in comparison to gravitational forces.

The importance of capillary forces depends upon the initial moisture content of the compacted clay before it is covered by waste material. If the higher hydraulic conductivity under saturated conditions can offset higher potential gradients but lower hydraulic conductivity under unsaturated conditions, the simple transit time equation may give satisfactory results. If, with reduced moisture content, the increase in capillary forces is greater than the corresponding reduction in hydraulic conductivity, this approach will under predict the transit time.

Although the D/V method may under predict transit time during the initial wetting period of a liner, the Agency believes that this method may be used to obtain reasonable estimates of liner performance. In addition, the method is simple to use and requires minimal data that should be readily available.

Transit time of liquids through a clay liner may also be affected by chemical interactions between the soil matrix and leachate. Such interactions may cause physical changes in the clay resulting in increased permeabilities and faster transit times.

Failure mechanisms of clay liners are defined as any interaction between waste liquids and compacted clay soil that can substantially increase the overall permeability of a clay liner and cause the liner not to meet the design requirements [EPA, SW-870, 1983].

There are a variety of other mechanisms by which a clay-soil-lined landfill can fail to prevent the escape of waste leachates. Seismic activity or subsidence can cause loss of the structural integrity of a liner. Tree roots, digging animals, or building activities may damage a landfill cover and allow the escape of volatile wastes. Various environmental conditions can affect the stability and strength of clay sidewall slopes, which may allow the lateral movement of waste leachates. There are still many unknowns with regard to waste containment. Because there are a variety of failure mechanisms that can cause clay liners to leak excessively, this section deals with effects on the permeability of clay liners caused by interactions with waste liquids.

Increases in the permeability of a compacted clay liner due to waste liquids are usually associated with a shift in the pore size distribution toward more macropores. Climatological cycles (such as wetting and drying, freezing and thawing, percolating rainfall that dissolves soluble soil components, etc) are widely understood to be responsible for the development of large pores and permeability increases in undisturbed clay soils [Brady, 1974]. These natural processes can be greatly accelerated in the context of a remolded and compacted clay soil exposed to waste leachates [EPA, SW-870, 1983].

The major mechanisms through which liners may be affected by waste liquids are:

- Increases in permeability throughout the liner due to volume changes that occur if the equilibrium swell/shrink of the soil/water system is affected when water is replaced by the waste effluent.

- Dissolution of clay liners brought about by an infiltrating chemical that dissolves the exposed surfaces of a pore or channel. Either organic or inorganic acids or bases may solubilize portions of the clay structure. Acids have been reported to solubilize aluminum, iron, alkali metals and alkaline earths while bases will dissolve silica. Because clay minerals contain both silica and aluminum in large quantities, they are susceptible to partial dissolution by either acids or bases. Dissolution may result in under-seepage and piping that may cause a shift in pore size distribution within the clay to macropores with no corresponding change in porosity. Such structural changes may result in increased permeability [EPA, SW-870, 1983].

Numerous studies have been conducted to determine the effect of various liquids, particularly organic liquids, on various clay liners. These studies indicate that such liquids, in many cases, will affect clay liners resulting in increased permeabilities [EPA, SW-870, 1983]. These studies, however, were conducted with reagent grade organic liquids and not aqueous solutions of the organics. Studies conducted using landfill leachates, where the concentration of organics range from parts per million to parts per thousand, have shown that clay liners are not affected by such aqueous solutions [Anderson, 1987]. This is further supported by field experience obtained in Wisconsin. Wisconsin, at one time, required compatibility testing between municipal waste leachates and clay liner materials. In tests performed at approximately 18 sites, the leachate did not result in increased permeability of the clay liners. In some cases, slight decreases in permeability were noted [Gordon, 1987].

Synthetic Liners

Synthetic liners include concrete, asphaltic concrete and geomembranes. Concrete and asphaltic concrete liners tend to crack and have poor resistance to many chemicals. Geomembranes are the most commonly used synthetic liners and will be the focus of this discussion [EPA, 530-SW-87-013, 1987].

The term geomembrane is often used by the engineering community in place of the term "flexible membrane liner" (FML). EPA is using the term "flexible membrane liner" or "FML" to be consistent with the terminology used in previous documents.

The Agency believes that based on current available information FMLs can, in thick enough guages, be expected to function as containment barriers for liquids [51 FR 10706, March 28, 1986]. Field experience to date reveals that FMLs have withstood a minimum of 27 years of exposure to severe environmental conditions (tropical exposure), while still remaining functional. Similar data on 20 years of exposure in a northern climate have shown negligible changes in strength [51 FR 10706, March 28, 1986]. Improvements in material formulations and the use of thicker gauges of materials should extend the expected life of FMLs beyond that of early materials that are still functioning today.

There are several documents, published principally for hazardous waste disposal, that contain information applicable to liner applications for MSWLFs. These documents contain very detailed and comprehensive information on such items as lining systems, liner materials liner performance, factors affecting liner performance, and construction quality assurance. These references are listed below with a notation as to their applicability to either soil liners or synthetic liners, or both:

U.S. Environmental Protection Agency, March 1983, Lining of Waste Impoundments and Disposal Facilities. Office of Solid Waste, Washington, D.C. EPA/SW-870, PB86-192796. (Synthetic and Soil Liners).

U.S. Environmental Protection Agency, April 1987, Bottom Liner Performance in Double-Lined Landfills and Surface Impoundments. Office of Solid Waste, Washington, D.C. EPA/530-SW-87-013. (Synthetic and soil liners).

U.S. Environmental Protection Agency, May 1987, Proposed Liner and Leak Detection Rule. Office of Solid Waste, Washington, D.C. EPA/530-SW-87-015. (Synthetic and soil liners).

Goldman, L.J., et al., August 1985, Design, Construction, and Evaluation of Clay Liners for Hazardous Waste Facilities - Draft. Research Triangle Institute, Research Triangle Park, NC. EPA/530-SW-86-007. (Clay or soil liners).

National Sanitation Foundation, November 1985, Standard 54 - Flexible Membrane Liners. Ann Arbor, Michigan. (Standards for synthetic liners (FMLs)).

2. Leachate Collection and Removal Systems

The volume of leachate produced at a landfill site is primarily a function of the amount of liquid that flows through the waste. In general, the more liquid that flows through the waste, the more contaminants will be leached out [Lu et al., 1985]. Landfills that are located in areas characterized by a high precipitation are more likely to generate leachate than arid areas. The leachate generated in a landfill will percolate downward through the refuse to the base of the unit, where it has the potential to enter the overburden and migrate to the aquifer.

In landfills designed with liners, or those with slowly permeable overburden, the leachate will accumulate to a depth that is controlled by the hydraulic conductivity of the liner or overburden. This situation results in a greater hydraulic head, equal to the depth of ponded leachate, increasing the driving force for leachate migration through the overburden. Leachate may also eventually back-up into the unit (i.e., the "bathtub" effect), that may result in basement seepage along various conduits such as pipeline trenches. Continued build-up into the unit could result in seepage through permeable strata near the surface, impacting surface waters or other possible receptors. In addition, units may be located in certain types of overburden, such as clays, that are not aquifer material but are saturated. Water from this saturated material will eventually seep into the waste and generate leachate if not controlled.

The conditions described above require the collection and removal of leachate to avoid the adverse effects described. A leachate collection system (LCS) generally consists of perforated drain pipe installed in gravel-filled trenches or on the base of the landfill (top of the liner). The collection system is drained by gravity to a sump or series of sumps from which the leachate is withdrawn. Additional details on the design and construction of leachate collection systems can be found in Lining of Waste Impoundment and Disposal Facilities [EPA, SW-870, 1983].

To minimize leachate migration potential, the Agency recommends that LCSs be designed to maintain less than one foot of head over the liner/base of the unit. This is the same performance standard required for Subtitle C facilities. Various technologies are available for meeting this requirement [EPA, 530-SW-85-014, 1985]. The LCS also should be capable of: (1) withstanding chemical attack from contact with the leachate, (2) withstanding the forces exerted by the wastes, equipment, and earth pressures, and (3) operating without clogging during the active life and post-closure care period of the unit.

There are various designs of LCS, for example the MSWLF case study sites consisted of three main designs:

- Perforated pipes placed in sand- or gravel-filled trenches;
- Perforated pipes placed on top of liners; and
- Sand- or gravel-filled trenches or french drains.

The three methods were used with approximately equal frequency. Leachate collection pipes typically consisted of perforated PVC, ranging from 4 in. to 6 in. in diameter. Drainage blanket or trench backfill material commonly consisted of poorly graded sand or gravel. Wisconsin was the only State having a specification for this material. This specification included a minimum permeability of 10^{-3} cm/sec and a maximum of 5% material by weight smaller than a No. 200 sieve. The density of collection pipes and trenches ranged from approximately one every hundred feet to a single collection point serving the entire facility.

Collected leachate can be either stored onsite in tanks or lagoons prior to disposal or discharged directly into a sewer for treatment at a municipal wastewater treatment plant. The most common method of disposal found in the case studies was treatment at municipal treatment plants.

The use of LCSs at MSWLFs is not a new concept. Based on the 1984 MSWLF facility survey, it has been estimated that:

- 15% of the active landfills are equipped with a LCS, and
- 27% of the planned landfills will be equipped with a LCS.

Of the 48 States that responded to the Survey, only 8 States do not have requirements for LCSs in either State regulations or guidelines.

3. Final Cover

The Agency believes that placement of a final cover over closed portions of a MSWLF is necessary to: (1) prevent or minimize infiltration of rainwater into the waste, (2) minimize dispersal of wastes by human, animal or physical interactions, and (3) minimize the need for further maintenance at the facility during post-closure and beyond. The types and amounts of cover material needed to accomplish these goals are highly dependent on the location of the landfill.

After closure, the key design element controlling liquids entering the unit is the final cover. The addition of water to wastes in a MSWLF accelerates the generation of leachate [Lu et al., 1985; Weiss, 1974]. The infiltration of water into the final cover and any subsequent percolation through the waste will be minimized by surface conditions such as soil type, soil thickness, final grade, type of vegetation, and climatic factors such as amount of precipitation, temperature, evapotranspiration, etc. For example, in areas with limited rainfall and high evapotranspiration, liquids entering the landfill after closure may be controlled by: (1) grading the unit in such a way as to promote runoff (2) using the proper type and thickness of soil to maximize moisture holding capacity, and (3) establishing vegetation to promote plant transpiration of water [McAneny, 1985; Lu et al., 1985]. In areas of high rainfall and low evapotranspiration, the above design factors may not by themselves be capable of minimizing percolation of water into the wastes. In such cases, additional design factors such as hydraulic barriers, either synthetic or compacted soils, and/or drainage layers may be necessary. [Dwyer et al., 1985; EPA, 600/2-79-165, 1979; McAneny et al., 1985]. Attachment 12 in Appendix A provides an example of a final cover design.

There are several methods by which the design and climatic factors affecting percolation and its relationship to leachate generation are analyzed. Two of these methods are discussed briefly here. EPA recognizes that there may also be other equivalent methods. Therefore, the use of any method, that demonstrates no water will percolate into the wastes after closure is believed adequate.

The first method was developed by EPA and is presented in Publication Number SW-168 [Fenn et al., 1975]. It is a manual water balance procedure for predicting leachate generation and is based upon the relationship among precipitation, evapotranspiration, surface runoff, and soil moisture storage. Precipitation represents that amount of water added. Evapotranspiration, the combined evaporation from the plant and soil surfaces and transpiration from plants, represents the transport of water from the earth back to the atmosphere, the reverse of precipitation. Surface runoff represents water that flows directly off the area of concern. The soil moisture storage capacity represents water that can be held in the soil.

The water added by precipitation will either evaporate directly back to the atmosphere from the soil surface, be utilized by plants through transpiration, serve to recharge a dried soil to field capacity (the maximum moisture content that a soil, or solid waste, can retain without producing continuous downward percolation), or become downward percolation or surface runoff. The relative amounts of each of these depends in large measure on the relationship between precipitation and evapotranspiration.

The water balance method centers around the amount of free water present in the soil. Until the field capacity of the soil is reached, the moisture in the soil is regarded as being a balance between what enters it as a result of precipitation and what leaves through evapotranspiration. If the monthly moisture loss from the soil through evapotranspiration is compared with the monthly precipitation, an accounting of the soil moisture can be made by a simple bookkeeping procedure. The moisture in the soil is analogous to a bank account where precipitation adds to the account, and evapotranspiration withdraws from it.

Because the precipitation and evapotranspiration are governed by different climatic factors, they are not often the same either in amount or in distribution through the year. However, almost all areas of the United States can be characterized by two seasons during the one-year cycle--a wet season and a dry season. During the wet months, precipitation will exceed evapotranspiration and water recharge to the soil will occur. During the dry months, there will be less precipitation and a high evapotranspiration demand will cause a moisure deficit in the soil. In most arid and semi-arid areas, moisture recharge during the wet season theoretically will be too small to attain field capacity, resulting in little or no water surplus. However, the opposite is true in humid areas, resulting in a definite downward percolation.

The equation by which percolation is determined is:

$$PERC = P - R/O - \Delta ST - AET$$

where

PERC = Percolation
P = Precipitation
R/O = Run-Off
ΔST = Change in soil moisture storage
AET = Actual evapotranspiration.

For a particular final cover design to meet optimum conditions, PERC should equal 0 at all times. When zero percolation cannot be achieved with an earthen cover, the owner/operator should consider the use of other means to control the excess moisture such as drainage layers or hydraulic barriers. Examples of how this method is used are presented in the document cited earlier [Fenn et al., 1975].

The second method, known as the "Hydrologic Evaluation of Landfill Performance" or HELP model, was developed for the Environmental Protection Agency by Paul Schroeder of the U.S. Army Engineer Waterways Experiment Station to estimate the amounts of surface runoff, subsurface drainage, and leachate resulting from the operation of a wide variety of possible landfill designs. The hydrologic performance of a landfill design with up to nine different layers can be modeled. Input parameters include type of layer, surface vegetation, thickness and soil type of each layer, and slope and drain spacing in the drainage layer. Site-specific precipitation and temperature data can also be entered in the model, or default climatic data for a number of cities can be used. Default data refers to data that are supplied by the computer program. For a detailed explanation of the HELP Model, the reader should refer to Schroeder et al. [1984a, 1984b].

The HELP model allows the user to specify the layers in a landfill design as one of five types: (1) vertical percolation (VP); (2) lateral drainage (LD); (3) barrier (B); (4) waste; or (5) barrier with an impermeable liner. A brief description of the layer types follows.

A vertical percolation (VP) layer allows vertical flow only. Water can percolate downward, or move upward and be lost by evapotranspiration. A VP layer is generally located at the top of the landfill cover to protect the lower layers and provide a medium for vegetative growth. This layer is usually moderately permeable. A lateral drainage (LD) layer is designed to intercept water percolating from the surface, and collect it by means of a network of perforated pipe or drainage tile embedded in the layer, for removal from the landfill. The model allows both vertical and lateral flow in the LD layer.

A barrier layer is designed to minimize vertical percolation of water in the landfill. A barrier layer in the cover is designed to minimize any water from reaching the waste layer, where it could then generate leachate. A barrier layer may be constructed of an impermeable material such as compacted clay or a synthetic membrane. The HELP model allows only vertical flow in a barrier layer.

A basic water balance equation that gives a simplified explanation of how the HELP Model simulates hydrologic behavior of a landfill cover is: Precipitation = Surface Storage (Snow) + Runoff + Surface Evaporation + Evapotranspiration + Subsurface Lateral Drainage + Cover Percolation + Stored Soil Moisture. The daily precipitation at a landfill site is the "input" to the landfill cover. The terms on the right side of the equation are the daily "outputs" of the landfill cover.

Again, as with the first method, the "cover percolation" term of the above equation in optimum conditions would equal zero (0). Applications of the HELP model are discussed further in the EPA Draft Technical Report on Evaluation of Landfill Cover Designs [Dwyer et al., 1985] and Covers for Uncontrolled Hazardous Waste Sites [McAneny et al., 1985]. Guidance on the design and construction of final covers can be found in these and other documents referenced in this section.

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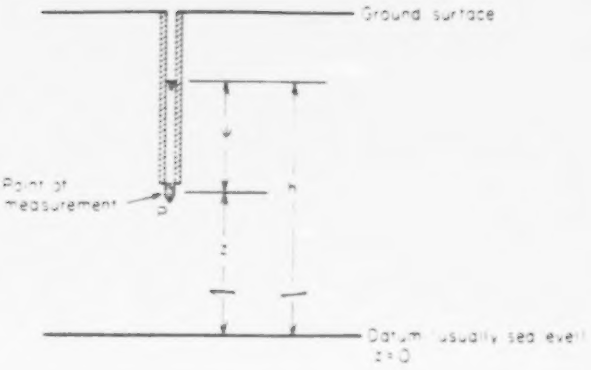
APPENDIX A.

ATTACHMENTS FOR SECTION III

Representative Values for Porosity

Material	Porosity
Coarse Gravel	28%
Medium Gravel	32%
Fine Gravel	34%
Coarse Sand	39%
Medium Sand	39%
Fine Sand	43%
Silt	46%
Clay	42%

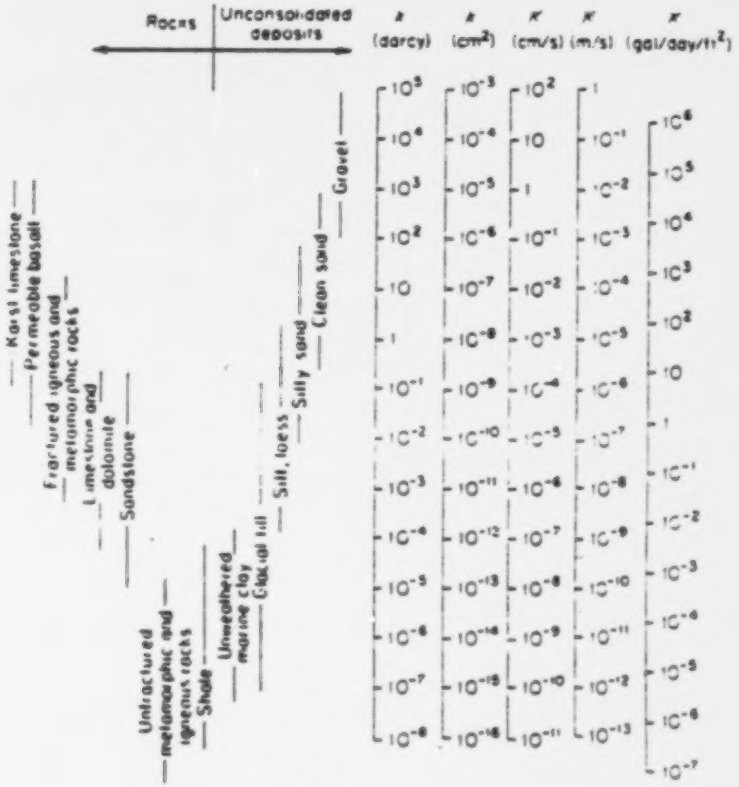
Attachment 2


Ground surface
ψ
h
Point of measurement
P
z
Datum (usually sea level)
z = 0

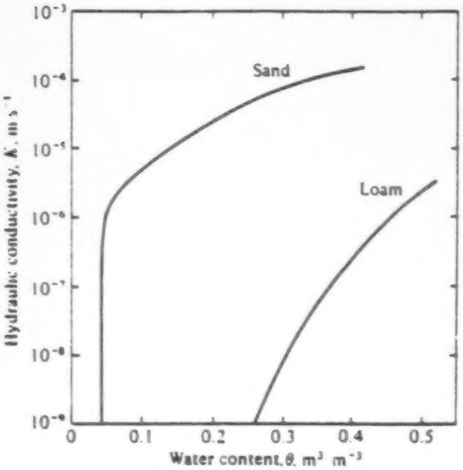
Hydraulic head (h), presure head (ψ), and elevation head for an unconfined aquifer. (Source: Freeze and Cherry, 1979)

Attachment 3

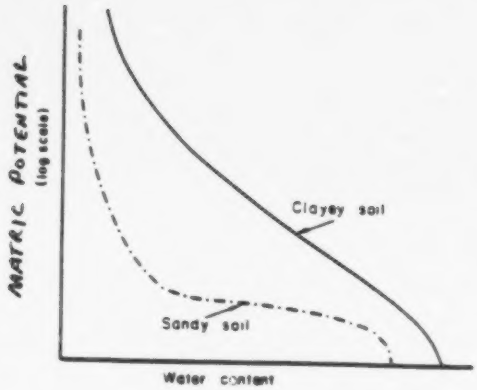
Representative Values for Saturated Hydraulic Conductivity
(Source: Freeze and Cherry, 1979)



Attachment 4



Dependence of Hydraulic Conductivity on Moisture Content for Different Textured Soils.
(Source: Marshall and Holmes, 1979)



Soil Moisture Characteristic Curves
For Clay And Sand Soils
(Source: Hillel, 1971)

Example Problem 1

This first problem provides an example of the procedure for calculating TOT through an unsaturated zone consisting of a single material type. A schematic of this single layered system is shown in Figure 4.2-1.

The following parameters must be known (either measured in the field or laboratory, or obtained from the literature) in order to apply this solution. Example values of each parameter are provided.

Parameter	Example Value
Flux (q)	0.5 cm/yr
Saturated water content (θ_s) for soil profile	0.31 m^3/m^3
The slope (-b) of a log-log plot of ψ_m versus θ	-3.162
Saturated hydraulic conductivity (K_{sat}) of the soil	5.4×10^4 cm/yr
Length of unsaturated column (L)	3760 cm

Step 1: Calculate m

$$m = \frac{1}{2b + 3}$$

$$= \frac{1}{6.324 + 3}$$

$$= 0.107$$

Step 2: Calculate Steady-State Moisture Content θ

$$\theta = \left(\frac{q}{K_{sat}}\right)^m \theta_s$$

$$= \left(\frac{0.5 \text{ cm/yr}}{5.4 \times 10^4 \text{ cm/yr}}\right)^{0.107} (0.31 \ m^3/m^3)$$

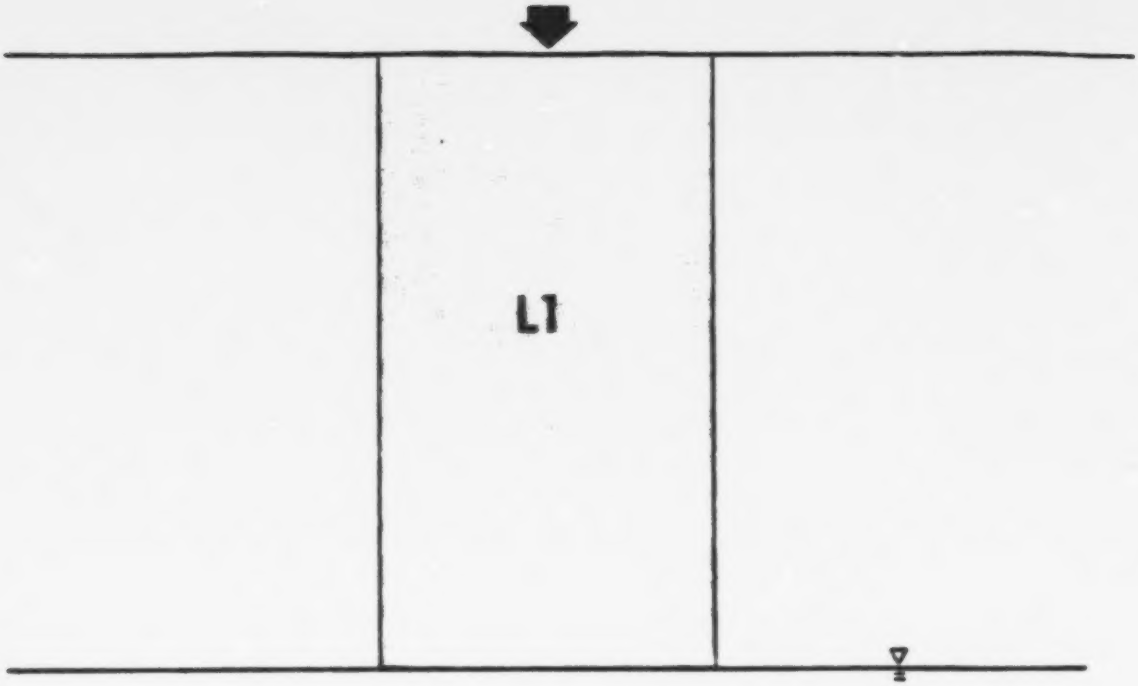


Figure 4.2-1. Schematic of Example Single-Layered System

$= 0.09\ m^3/m^3$

Step 3: Calculate Travel Time (T)

$$T = \frac{L\theta}{q}$$

$$= \frac{(3760\ cm)(0.09\ m^3 m^3)}{0.5\ cm/yr}$$

$= 677$ years

Example Problem 2

This second problem is similar to the first except that it illustrates the procedure for calculating TOT through a multi-layered unsaturated flow system. A schematic of this multi-layered system is shown in Figure 4.2-2.

The following parameters must be known in order to apply this solution. Example values of each parameter are provided.

Parameter	Value	Notes
Flux (q)	0.5 cm/yr	Constant throughout section
Saturated Water Content		
θ_{s1}	0.31	
θ_{s2}	0.40	
θ_{s3}	0.42	
Slope of log-log plot of ψ versus θ(-b)		
b_1	-3.162	
b_2	-3.475	
b_3	-3.610	
Saturated hydraulic conductivity (K_{sat})		
K_1	5.4×10^4 cm/yr	
K_2	1.0×10^4 cm/yr	
K_3	0.5×10^4 cm/yr	
Length of unsaturated column (L)		
L_1	1,000 cm	
L_2	1,000 cm	
L_3	1,760 cm	

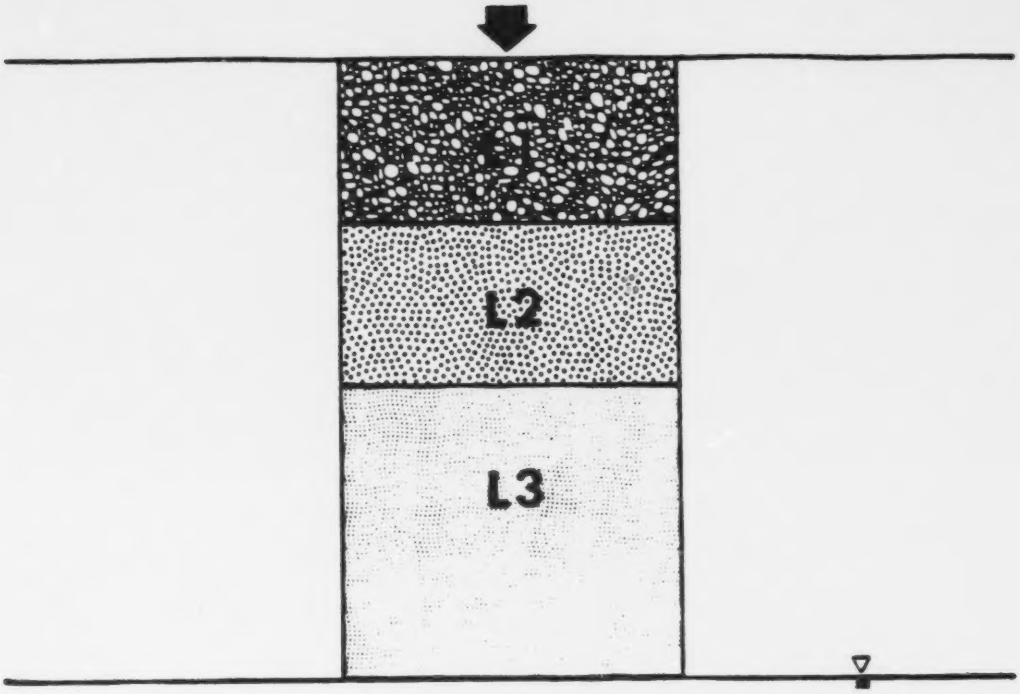


Figure 4.2-2. Schematic of Example Multi-Layered System

Step 1: Calculate m for Each Layer

$$m = \frac{1}{2b + 3}$$

$m_1 = 0.107$

$m_2 = 0.101$

$m_3 = 0.098$

Step 2: Calculate Steady-State Moisture Content for Each Layer

$$\theta = \left(\frac{q}{K_{sat}}\right)^m \theta_s$$

$\theta_1 = 0.09$

$\theta_2 = 0.15$

$\theta_3 = 0.17$

The total travel time through the section in the sum of the times through each of the layers.

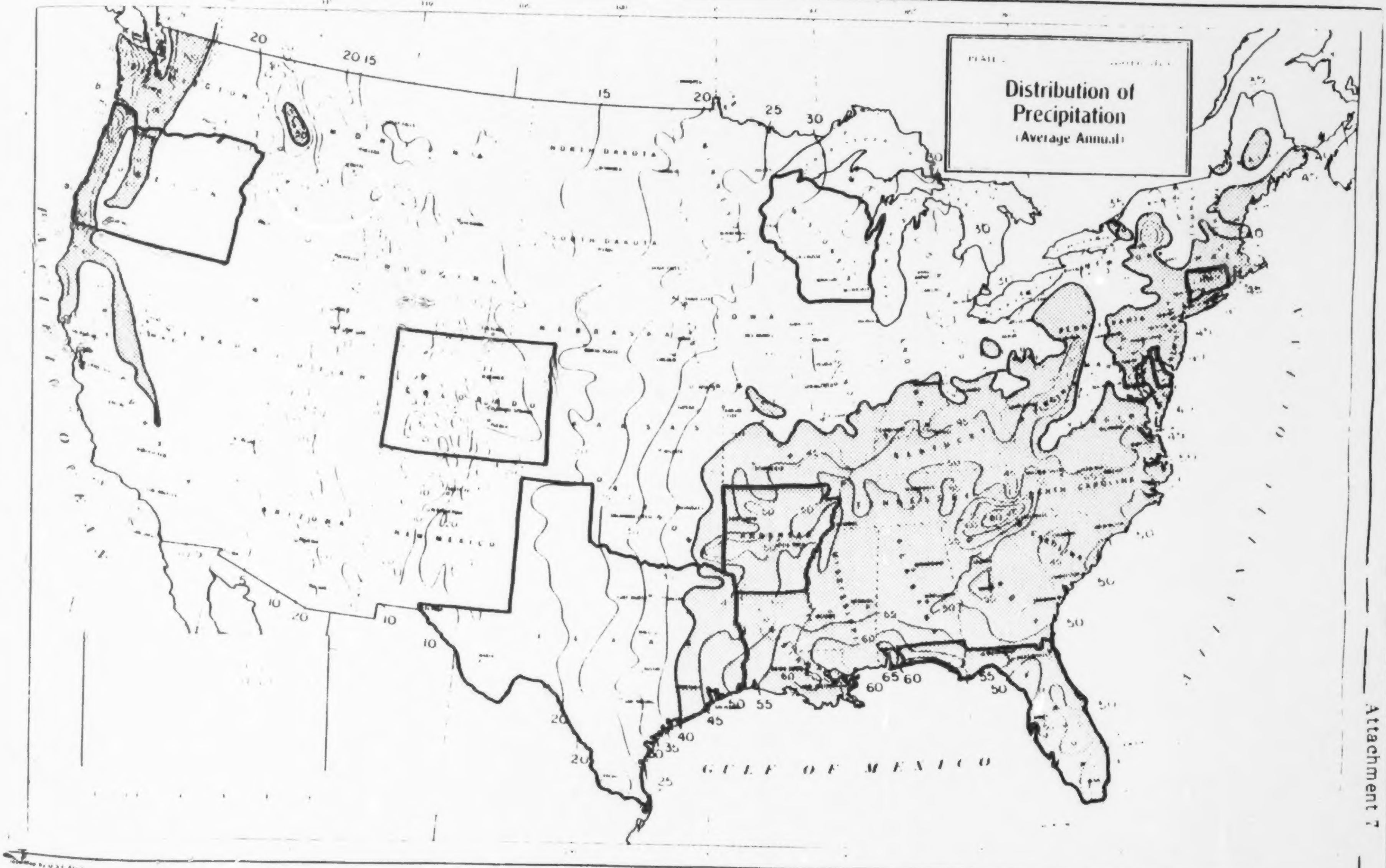
Step 3: Calculate Travel Time (T)

$$T_1 = \frac{(1{,}000 \text{ cm})(0.09)}{0.5 \text{ cm/yr}} = 180 \text{ yr}$$

$$T_2 = \frac{(1{,}000 \text{ cm})(0.15)}{0.5 \text{ cm/yr}} = 300 \text{ yr}$$

$$T_3 = \frac{(1{,}760 \text{ cm})(0.17)}{0.5 \text{ cm/yr}} = 600 \text{ yr}$$

$$T = T_1 + T_2 + T_3 = 1{,}080 \text{ yr}$$


Distribution of Precipitation
(Average Annual)
PACIFIC OCEAN
GULF OF MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
IOWA
NEW MEXICO
NORTH CAROLINA
20
20 15
15
20
25
30
30
10
20
10
10
20
20
25
35
40
45
50
55
60
65
60
55
50
50
50
50

***NOTE:** Shaded areas indicate those areas that receive 40 or more inches of precipitation per year.
Outlined States depict those States included in the MSWLF case study.

BACKGROUND DOCUMENT

"CRITERIA FOR MUNICIPAL SOLID WASTE LANDFILLS"

SUBTITLE D

EVALUATION OF LEACHATE GENERATION BASED ON ANNUAL PRECIPITATION AT MUNICIPAL SOLID WASTE LANDFILLS

PREPARED BY:

NUS CORPORATION
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GAITHERSBURG, MD

FOR:

U.S. ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF SOLID WASTE
August 1987

Attachment 8
(Cont.)

DRAFT
AUG 10 1987

EVALUATION OF LEACHATE GENERATION
BASED ON
ANNUAL PRECIPITATION AT
MUNICIPAL SOLID WASTE LANDFILLS

The 116 municipal solid waste landfill (MSWLF) case studies have been reviewed to determine if a cut-off value can be defined for determining when a leachate collection system (LCS) is necessary. Facilities that recieved any liquid waste were removed from this evaluation because liquid wastes would impact leachate generation and a true relationship between precipitation and leachate accumulation could not be made. This left 91 case studies for the evaluation. Additional case studies were then deleted from the evaluation based on other factors identified in the facility files besides the receipt of liquid wastes that could impact leachate generation. These factors included: the waste was placed directly in the groundwater; the facility received waste types that could not be identified (possibly liquid waste); the facility was not operated long enough to allow leachate time to generate and accumulate; operating procedures (e.g., final or daily cover) may have impacted leachate generation; or the LCS was used to collect surface run-off in addition to leachate, thus giving inaccurate results of leachate generation. Other case studies were removed from the evaluation because the facility files did not have sufficient information to analyze whether leachate was being generated or not.

The attached tables (Table 1) provide the name of the facility and State, the date the facility first operated, the amount of precipitation received per year, whether leachate generation is indicated, whether a LCS is in place, remarks that provide more detailed information on the facility, and reason why the facility was removed from the evaluation.

Thirty-one facilities were evaluated to determine whether leachate accumulation or problems associated with leachate existed. Seven facilities were located in areas that received less than 40 inches precipitation per year. Four of these seven facilities had information in their facility files indicating the facility was not accumulating leachate in appreciable amounts. Either leachate generation was noted to be minimal or ground-water monitoring results indicated that leachate

DRAFT
AUG 10 1987

had not contaminated the ground water. Almost half of the facilities that receive 40 and above inches per year of precipitation showed significant leachate accumulation ranging from 7,200 gallons per year to 41.0 million gallons per year. The other half did not have data on the amounts of leachate generated, but ground-water contamination due to the leachate had been documented. Five of these facilities had been ordered closed due to the ground-water contamination. There were three sites in Wisconsin that receive approximatley 30 inches of precipitation per year and show leachate accumulation. However, another facility that receives approximately 32 inches per year of precipitation does not show any leachate accumulation and ground water has not been impacted due to leachate. Table 2 provides information on the amount of leachate generated at each facility, if available, or whether problems associated with leachate have been identified for these 31 facilities.

It appears from this limited set of data that facilities located in areas that receive 40 inches/year of precipitation or more generate leachate in appreciable amounts that warrant collection. However, the converse does not appear to be as clear for areas that receive less than 40 inches/year.

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES

#	Facility Name	State	DFO	P	LI	LCS	Remarks
1	North Delta County[a]	CO	1930s	8	N	N	• The disposal method involves a filling sequence which includes 7 lifts • The facility does not have a liner and leachate collection system • Surface water runon/runoff will be controlled by drainge facilities • No surface water monitoring • Groundwater monitoring system presently consists of 1 downgredient and hyogradient monitoring wells There will be two more wells added • The quality of groundwater is poor: it contains very high concentrations of dissolved solids • No quarterly groundwater monitoring data are available in the CDH file
2	Knott Pit[a]	OR	1972	12	U	N	• The facility disposes of solid and sewer solid wastes in cells and placed septic tank wastes in a lagoon to solidify • The landfill stopped accepting septic tank wastes in the Spring of 1986 • Most of rainfall occurs in the Winter • The landfill is located on a flatside with lava underlying sandy and gravelly material • There are no liners and leachate collection systems on the site)occording to DEQ, the several hundred feet of lava between the landfill and groundwater provides a sufficient barrier to prevent groundwater contamination) • The static groundwater level is about 125 feet below the surface • There is no information on the lagoon available • There are no runon/runoff controls because the annual water evaporation rate is greater (22.4 inch) than the annual precipitation rate.
3	Yuma County[a]	CO	1982	15	N	N	• There is no liner or leachate collection system on the site • Groundwater is located 66 feet below the surface of the site and is protected by a layer of impervious siltstone bedrock • There is 1 well located in the vicinity of the landfill and a total of 13 wells within 1 mile radius of the site. • The only moisture entering the landfill is in the form of precipitation. Most of this precipitation is diverted away from the trenches via drainage ditches • The adjacent well (providing the water supply for the site) is monitored. Upgradient groundwater samples are taken from an existing well southwest of the site. water is tested according to Colorodo Shore Health Dept. standards. No data is available

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
4	Midland[b]	TX	1985	15	U	N	• The cells of the landfill are lined with 18 inches of clay and a 0.03 inch polyvinyl chloride liner • The quality of groundwater is rated as fair quality drinking water • Groundwater is located 34 to 58 feet below the surface • Runoff/runon control is assured by 12 inch high barriers constructed from well-compacted clay built around the cells. Rainfall into cell areas is pumped out and sprayed onto previously filled areas. • There are 4 monitoring wells and 5 boreholes on the site • No groundwater monitoring data are available • Historically, this area has shown no fault activity
5	Landfill Systems, Inc.	CO	1984	15	Y	N	• The landfill is equipped with a compacted clay liner and a compacted soil cap • There are drainage control facilities that consist of retention ponds and diversion channels • The facility has both surface water and groundwater monitoring programs • The potential for contamination of ground and surface water is very low, due to the site's hydrogeology (The impermeable nature of the underlying bedrock and the significant depth of the shallowest drinking water aquifer) • There is no surface water within the property • The amount of generated leachate seems minimal • The site's ground-water monitoring system consists of 9 wells, 4 wells monitor conditions in the soil and 5 wells monitor conditions in the bedrock • The system is to be monitored on a quarterly basis • The quality of groundwater is relatively poor • Groundwater occurs at depths of 400 to 480 feet below ground surface in the landfill area
6	West Garfield County[a]	CO	1982	16	U	N	• The landfill has 17 solid waste disposal sections. One section contains 3 sludge ponds • There is no liner or leachate collection system for the solid waste sections • The sludge ponds have 12 inch clay liners compacted to 90% of standard proctor desity • There is no information available on the site's geohydrology • Runoff/Runon is controlled by drainage diversion ditches constructed around the landfill

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
6	West Garfield County[a] (continued)						• There is a groundwater monitoring system however, the data are not available • There is no indication of a surface water monitoring system • There is no information on leachate
7	County Line[c]	CO	1980	17	U	N	• Surrounding groundwater is used for residential and other purposes • There is no liner on the site (it was not required) • There are 3 water-bearing zones at the landfill: shallow, intermedite, and deep • No information on runon/runoff control is available. Natural drainage through the site is impeded. • Six groundwater monitoring wells are in place • Groundwater, particularly in shallow zone, indicated high level of contamination caused by the infiltration of surface water into the refuse • A dewatering system and water treatment for the site was recommended
8	Van-Dal[a,f]	CO	1980	19	Y	Y	• The site was evaluated as having a high potential for problems with runon and runoff • The site also, according to DMD was a poor candidate for a solidwaste disposal site. Nevertheless, CMD approved the site for use as landfill in 1979 • Part of the landfill (Phase I) is full and in the process of being closed • LCS only collects surface leachate • There were problems with leachate seeping through the settling ponds and running to two rivers • There were problems with leachate control devices • There are no wells in the area because of the lack of groundwater in the shale bedrock • There is no constructed liner • The landfill permit application stated that there will be a 2 to 6 feet thick clay underneath any cell • There is a surface leachate reservoir on the landfill • The leachate was pumped to sprinklers and sprayed back over the lanfill • The landfill is located in the area occasionally covered with surface water flow • Runon/runoff controls are in places • There is no information available on groundwater monitoring data; no monitoring data are collected at the landfill

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
9	Quail Canyon	TX	1977	20	N	N	• The site, part of an existing facility, has a waiver on liner requirements based on water balance calculations • Depth to local water table ranges from 47 to 105 feet below the existing ground surface • Original portions of the site fall within the 100 yr flood plain • Information on original design was not available • No leachate collection system is present on the site • There were 6 groundwater monitoring wells installed on the site. The wells were sampled every 6 months The results do not indicate groundwater contamination
10	South Stage[a]	OR	1962	20	Y	N	• Groundwater occurs at depths of 36, 46, 64 feet. The steptic groundwater level in one well is approximately 25 feet below ground surface • Leachate seeps, due to runoff, have been observed below the disposal area but no monitoring data are available to confirm ground or surface water contamination • The site is not equipped with a liner and leachate control system • There is no monitoring program at the site • No sampling and analytical data are available for the leachate or surface waters in the area • The control of surface runon/runoff does not work properly There are plans for a new concrete division drain and storage pond for a new disposal area • No monitoring had been required and conducted until November 1985, DEQ recommended implementation of groundwater monitoring programs
11	Fox Hill[c]	OR	1950s	20	Y	Y	• The landfill is unlined except that areas of exposed bedrock are sealed with clay • A clay berm and liner were installed at the base of the disposal area. The extent of the lined area is unknown • Depth to usable groundwater is approximately 130 feet • Shallow groundwater was discovered upslope of the active disposal area. Drains were installed to dewater this area. This lowered the water table at least 10 feet • The property boundary is approximately 300 feet from the Gronde Ronde River

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
11	Fox Hills[c] (continued)						• The landfill is a former open burning dump • A leachate seep developed downslope of the shallow groundslope of the shallow groundwater area (2 feet) and discharged at approximately 2 to 5 gal/min Installation of the drains has effectively stopped the leachate seep • Most of the precipitation occurs during the winter months and,due to low PET, results in a total cummulative moisture surplus of approximately 10inches • There are 4 water supply wells located adjacent to and downslope of the site • The landfill is located in an intermittent drainageway, surface runoff that collects in the drainageway discharges to Haywire Canyon and then to the Grande Ronde River • Several drainage ditches, easements, and berms were constructed to reroute runoff • A clay lined cutoff dike directs seasonally-perched and runoff waters into the diversion ditch • The leachate collection system consists of a clay berm underlain by a leachate drain pipe The pipe discharges to a leachate collection pond • There are some monitoring wells on the site, however, no details are available • The only analytical results that are available are those at the interceptor bench, these results indicate high mineral content due to old ash from burning operations and do not indicate leachate contamination
12	Summit County[a]	CO	1979	22	U	N	• The site does not have a liner because of the impervious nature of shale bedrock that is found at shallow depths 5 to 10 feet throughout the site • Surface water from above the landfill is diverted around the site by man-made ditches • The landfill accepts, among other wastes, liquid sewage sludge • There are 6 groundwater monitoring wells. Water was found in only four of these wells • Investigation has determined that, with proper surface water diversion controls, it was unlikely that the ground water would be affected by landfill operations • There are no data on water quality

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
12	Summit County[a] (continued)						• The proposed lagoon for emergency storage of liquid sludge included a shale liner 2 feet thick at the bottom and 10 feet thick at the rim • Runoff will be controlled by drainage barriers in the drainage bottoms of the fill areas
13	Nelson Gardens[a]	TX	1980	28	N	N	• Liner- lined with equivalent of 3 feet of clay having permeability of less than 1 x 10^{-7} cm/sec • GWM data insufficient - most times no water in well to sample • Major aquifer in area is 1,300 to 1,600 feet beneath the site
14	Tessman Road	TX	1981	28	N	N	• Liner - at least 3 feet of soil having a permeability not less than 10^{-7} cm/sec (In-site soils used) • Major aquifer is located approximately 1,300 feet beneath the site • No GW contamination indicated • No problem with leachate identified in file
15	Pearsall Road[d]	TX	1979	28	Y	N	• The site is partially lined, only sides are lined, bottom is not lined • No data on the actual wastes received • Surface seepage of leachate has occured • Survey conducted in 1985 indicates leachate is migrating downward to water table - extent and amount unknown
16	Laidlaw Waste Systems, Inc.[a]	TX	1980	30	N	N	• Southern portion of site located in flood plain (levee used as protection) • Liner - at least 3 feet of clay with permeability of 1 x 10^{-7} cm/sec • No gwm perfomed
17	Black River Falls[e]	WI	1943	30	Y	N	• No liner or LCS • Located in highly permeable alluvial sands • GW 15 to 53 feet deep • Domestic wells 300 to 500 feet away, contaminated • Sand used as final cover until 1979 • Final cover not properly drained to prevent ponding
18	West Bend[a]	WI	1964	30	Y	N	• Probably no liner or LCS • Subsoils range from clay silts, to coarse sand, to fine sand • GW 11 to 96 feet deep • 7 private wells show VOC contamination • Final cover was to consist of clay

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

Attachment 8
(Cont.)

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
19	Winnebago County[c]	WI	1971	30	Y	Y	• 1/3 of wastes were industrial sludges • STP sludges also accepted • Wastes placed both above and in GW with LCS • Leachate = 32,400 gpd
20	Marathon County	WI	1980	30	Y	Y	• 1/4 of wastes are industrial sludges • 4' clay liner and LCS • Approx. 1 MGY leachate collected About 2.7 in/yr accumulation • Clay cap at closure
21	Ridgeview Regional[b]	WI	1985	30	N	Y	• Old LF began in 1980 and accepted liquids • New areas are lateral expansions started in 1985 with clay liners (2) and LCS • GW contamination from old site • No leachate generated yet cost estimates based on 2.4 MGY of leachate
22	Brown County East	WI	1976	30	Y	Y	• Approx. 50% industrial wastes • Clay liner and LCS • Approx. 2 MGY collected, Approx. 1.27 inches/year • Base approx. 10 feet above gw
23	Dane County (Verona)	WI	1977	30	Y	Y	• 2' low permeability soil under waste • 0.25 MGY leachate generated • LCS is pipes in trenches
24	Delafield[d]	WI	1976 1956 unlined	30	Y	Y	• Consists of both lined and unlined areas • Lined areas w/o QA/QC or plans until 1977 • LCS installed 1978 • 0.64 MGY leachate collected since closure • Sections of old lined areas may be in gw • Initial final cover included sands - clay added in 1980
25	Dry Creek[d]	OR	1972	30	Y	N	• No engineered liner • Leachate surface seeps have occurred due to inadequate cover application,compaction of waste and run-off system • Available GWM results are inadequate to show gw deterioration • Insufficient information to determine the amounts of leachate generated or extent of contamination

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
26	Seven Mile Creek[d,f]	WI	1978	31	Y	Y	• On-site soils are sands & silts • Clay liner 4'-5' • LCS is pipe covered by sand blanket • Precipitation on active portion collected by LCS • Leachate collected, 1 3 MYG-(1983) Approx 3 65 inches accumulated • Receives a considerable amount of papermill sludge • Leachate generated and collected was very mild • Final cover on initial phases was papermill sludge which was too permeable • Daily cover = sand
27	Sunset Farms	TX	1981	32	N	N	• Liner, at least 3 feet of clay with permeability of at least 10^{-7} cm/sec (in-place soils used) • Site designed to minimize leachate generation • GWM conducted no impact to gw
28	City of Saint Jo[b]	TX	1985	32	U	N	• Liner not required because no significant leachate production is anticipated • No GWM conducted • Not operated long enough to indicate any problems
29	City of Abbotsford[f]	WI	1982	32	N	Y	• 3' clay liner & LCS • Very small operation, approx. 35 tons/week • LCS used for run-off collection system • Only open 2 days/week
30	Portage County[f]	WI	1982	32	Y	Y	• 5' clay liner & LCS • LCS used as run-off collection system • Some leachate in collection system tanks
31	Sank County[a]	WI	1973	32	Y	N	• Closed 1981 beause of GW contamination • No liner or LCS • On-site soils sandy • No other data • Run-on/off controlled because of erosion
32	Milam County[b]	TX	1985	34	U	N	• No liner required, because no significant leachate production anticipated • No GWM conducted • Not operated long enough to indicate any problems
33	DFW[a,e]	TX	1972	34	Y	Y	• Most of surrounding land in flood plain • Liner 3 foot clay with permeability of 1×10^{-7} cm/sec • Actual data on waste volumes & types not available • Information on operation of LCS unknown (only designs available) • Amount of leachate generated unknown • GWM conducted increased mineralization indicated

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
34	Lacy-Lakeview[b]	TX	1985	35	U	N	• Natural liner • No significant leachate production anticipated • Not operated long enougn to endicate any problems
35	Short Mountain[f]	OR	1976	36	Y	Y	• No synthetic or engineered liner - inspection in 1983 indicated waste placed directly on top of existing ground surface (clay, mudstone, sandstone and volcanic rock) • Southwestern part located in flood plain • Originally wood chips used as daily cover • Leachate, contaminated surface water & run-off directed to same leachate lagoon • Leachate flow has been measured as 8.2MGY (includes run-off) • Leachate stored in winter months and is disposed by irrigating adjacent land
36	Victoria City[a]	TX	1982	37	Y	N	• File did not indicate actual characteristics and quantities of waste received • Natural liner - at least 3 feet of in-place clay-rich soils • GWM results indicates increases in several parameters suggestive to leachate contamination • Insufficient gwm data to confirm contamination of ground wate due to leachate • Depth to gw 35 to 38 feet
37	Sandtown (CSWF-1)	DE	1980	40	Y	Y	• 20 to 200 GPD (leachate) fluctuates widely • 30-mil PVC liner • GWM system installed • No GW contamination detected
38	Coffin Butte	OR	1953	40	Y	Y	• 8.0 MGY (leachate) mostly in winter • Located in an old quary • Natural clay liner • Leachate holding lagoons expanded in 1984 to reduce impacts to surface water • French drain LCS (down-gradient) with sumps
39	Saint Johns[a]	OR	1932	40	Y	Y	• Applied for permit in 1970 for expansion • Located in flood plain & wetlands • EPA allowed expansion after several years of negotiation • Original 181-acre site has no liner or LCS • 55-acre expansion has a LCS and a 5,000-foot dike around its perimeter, no liner mentioned • Groundwater is considered contaminated, no additional impact is expected since ground water is considered an unusable source • Amount of leachate generated unknown • Leachate sent to treatment plant

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
40	KFD/Reidel	OR	1979	40	Y	Y	• Liners consist of compacted clay on bottom and synthetic membranes along sides (36 mil) installed to minimize the amount of leachate dischared from landfill • LCS installed to prevent 'bathtub' effect • Leachate had been recirculated but ordered by DEQ to treat leachate because the recirculated leachate was increasing in strength and caused odor problems • Amount of leachate generated or LCS & treatment system not described in facility file • GWM conducted - monitoring results indicate elevated levels of some parameters (e.g., COD and iron) but no background data available and can not assess impacts to ground water
41	Roseburg Central	OR	1978	40	Y	Y	• Leachate generation is a significant problem at the site and has resulted in contamination of surface water and groundwater • Current LCS is inadequate for collecting leachate (consists of a perforated pipe placed along bottom of the canyon) • Improvements to LCS and treatment being designed in an attempt to correct contamination problems (requred by DEQ) • Currently leachate is collected and disposed of by irrigation on completed fill (amount Unknown) • No synthetic or engineered liner required in permit - file has no information on liner
42	Woodburn[a]	OR	1974	40	Y	Y	• Natural clay compacted liners • LCS - triangular drainage ditches at bottom of trenches and drain curtain • Perched water exists at site and causes wetness problems in the wet winter months (results in odors & possible gw contamination) • Poor soil drainage present at site • Leachate disposed of by irrigating on closed sections of landfill • Amount of leachate generated unknown • GW monitoring results indicate several parameters, notably color, iron, COD and TOC present in elevated levels that suggest leachate contamination, however no background data available to confirm contamination • Corrective action to improve LCS and drainage control

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may havecontributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

Attachment 8
(Cont.)

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
43	Grants Pass	OR	1967	40	Y	N	• Located on federal land • Wet season October to March • The cells are apparently unlined • Leachate is controlled by 1) surrounding active cells with 3-foot high berms, and 2)using drainage ditches to route run-off from active cells to an onsite lagoon • Two internal memoranda by DEQ to the Solid Waste Division indicate that there is potential to contaminate gw by infiltration into the soil and surface water by leachate collection • GW monitoring results indicate ground-water contamination due to leachate. This is tentative since the location of monitoring wells is unclear
44	Shelton	CT	1970	41	Y	N	• No liner or LCS (only requrement in permit is 5 feet of clean fill be maintained between the bottom of deposited solid waste & the high ground-water level or bedrock) • Groundwater contamination due to leachate has been confirmed • Contamination of gw is limited to site boundary • Amount of leachate generated unknown
45	Brown's Island	OR	1967	41	Y	N	• Located in gently-rolling flood plain about 1/4 mile from large river (2 year flood) • Liner consists of 5 feet layer of soil with moderate permeability • Liner is used to remove contaminates from leachate as it passes through rather than retain leachate • If liner were impervious leachate would back up due to high prec. & cont. surface water • Groundwater contamination due to leachate well documented at site since 1974 • Contaminated groundwater (leachate) is moving from the site to the Willamette River has been estimated to be from 1 2 to 7 5 MGD • Site scheduled for closure in May 1986. Final cover is expected to reduce amount of precipitation infiltration and thereby reduce the amount of leachate produced
46	Cherry Island (NSFW-2)	DE	1985	42	Y	Y	• 30,000 gpd of leachate (10 9 MGY) • A leachate collection grid is used to collect leachate then pumped to local wastewater treatment plant System of stone-filled trenches and pipes • Existing dredge spoil materials used a s natural liner(30 to 80 feet thick)

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

Attachment 8
(Cont.)

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
47	Wilton	CT	1966	42	Y	N	• Constructed in wetlands • No information in file on liner (assumed no liner installed) • Surface water contamination due to leachate confirmed in 1970 • Ground water contamination identified in 1976 • Landfill ordered closed in 1976 due to contamination problems
48	Pidgeon Point (NSWF-1)	DE	1968	42	Y	Y	• Natural liner(dredged spoils) • Retrofitted with LCS in 1972 and upgraded in 1981 • LCS consists of perforated PVC pipe on a stone-filled trench. Five pump stations are used to collect leachate • 1.15 MGY of leachate
49	Fort Smith, Ft. Chaffee Site[a]	AR	1981	43	U	N	• No liner installed • No LCS required according to site plans but would be installed if leachate contamination of monitoring wells becomes a problem • Unknown if leachate is generated • GWM data extremely limited
50	New Milford[a]	CT	1966	43	U	N	• No liner installed (5 feet of clean fill) • GWM has indicated isolated elevated levels of contaminants have occurred in some sampling rounds
51	Rusk County[b]	TX	1985	43	U	N	• In-situ clay liner • No GWM conducted because no significant hazards to gw or sw anticipated due to presence of clay liner • Can not determine if leachate is being generated (no data)
52	Pine Hill[a]	TX	1981	43	Y	N	• In-situ clay liner (minimum of 3 feet) • GWM conducted - (1984-5) no background data available therefore GWM data insufficient • Results of GWM are generally not indicative of 'gross leachate concentration' • Unknown from available data how much leachate is being generated
53	Canton	CT	1965	43	Y	N	• No liner • GWM indicated leachate has contaminated groundwater & surface water • Due to contamination,site was ordered closed in 1981 • Ordered to provide alternate potable water supplies to businesses east of the site

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
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e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
54	Lichfield	CT	1930	43	Y	N	• No liner (native soils) • Groundwater contamination due to leachate detected in 1981; surface water contamination detected in 1979 • Consent order issued by DEP required closure of 50% of the facility in 1984 because of leachate contaminate and remainder closed within 5 years
55	Hartford	CT	1976	44	Y	N	• No liner • Located over permeable soils on a flood plain protected by flood dikes • Groundwater quality has been impacted by leachate, however, impact to Connecticut River considered negligible
56	River Bend[a]	OR	1982	44	Y	Y	• Liner - 1 foot of compacted on-site clay • Due to perched water, dewatering devices used when constructing cells • Due to heavy rainfall (mostly between October and May) leachate generation is a problem & LCS is employed • Data on amount of leachate generated not available in file • LCS consists of 8 to 10-inch diameter perforated pipes and gravel drainage blankets leachate is pumped from collection pipes to holding lagoon (size unknown)
57	R-L-H, No. 2[a]	AR	1982	45	U	N	• No liner -native clays (2 feet of well compacted clay) • Unknown if leachate is being generated • Because of the characteristics of the limestone bedrock, the location of the ground water table varies from location to location and cannot be reliably established • GWM data not conclusive
58	Parsons[b]	AR	1980	45	U	N	• Liner - clay compacted to a 90% protor density • Amount of leachate generated unknown • Landfill only operational for 2 years - gwm indicates no impact, landfill not operating long enough to show impacts • Depth to water table greater than 100 feet
59	South Windsor	CT	1950	45	Y	N	• No liner • Due to high ground water elevation, leachate frequently discharges into storm water drainge ditch • Leachate generation estimated to be 50,000 to 100,000 gpd • Site closed in 1979 due to groundwater contamination

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
60	Tolland	CT	1965	45	Y	N	• No liner • No engineering design plan • Extensive groundwater contamination due to leachate • Ordered to close in 1979 by DEP
61	Carrol County	AR	1972	45	Y	N	• No liner - natural clays • Leachate problems have contaminated surface water from the toe of the fill • LCS was to be installed based on site plan but no indication if has been done • Consent Order issued by ADPCE in 1985 indicated continuing problems with leachate control • Site closed in 1985
62	Howard County[a]	AR	1976	46	U	N	• Natural clay liners with minimum thickness of 2 feet • No GWM conducted • No data available on whether leachate is generated • Nearest aquifer is 200 feet below the surface and is isolated hydrologically from the landfill by beds of low permeability clay and limestone
63	Chamber County[b]	TX	1984	48	U	N	• Natural clay (in-situ) liner at least 3 feet thick • Part of landfill in flood plain-leves used to prevent flooding • Leachate not monitored, unknown if generated • No monitoring wells required
64	Morrilton,No.2[a]	AR	1983	48	U	N	• Liner - natural in-situ soils • Unknown if leachate is generated, not monitored • GWM data inconclusive
65	Cleburne County L & H[a,d]	AR	1982	48	Y	N	• Portions of site considered to be in flood plain • Liner - maintain at least 1.5 feet of native sandy clay soil above the clayey sand or weathered sandstone • GWM results (1985) showed elevated levels which are indicative of contamination- erosion and inadequate vegetative cover at closed out areas determined to be the problem
66	United Sanitation, No.2[a]	AR	1979	50	U	N	• Clay liner installed • No information available on leachate generation • GWM data not conclusive only have data for 1984
67	Shannon Road[a]	AR	1976	50	U	U	• Insufficient information in the file on design, operation, etc.

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
68	Benton[a]	AR	1982	50	U	U	• Liner information not available • Insufficient information in the file
69	Phillips County[a]	AR	1979	50	U	N	• Liner recompacted upper 6-8 inches of soil • No monitoring information available • Insufficient information in the file
70	East Pasco County	FL	1975	50	Y	Y	• Abandoned site operated 1970-1975 • Closed site capped in 1982 • Existing (operating) site constructed 1982 • 2 liner systems: 20-mil PVC sidewalls with 30-mil PVC base • 2 types LCSs: natural drainage system directs leachate to sumps, and constructed drainage system directs leachate to dumps • Estimated leachate: 1.94×10^7 gpy in 1983 (natural-drainage LCS); 1.03×10^7 gpy in 1987 (constructed-drainage LCS). • Fate of collected leachate not clear from information in files • Very little monitoring data, but data for well samples indicate that the samples meet class 2 GW standards for all tested parameters except iron and pH.
71	Hillsborough Height	FL	1979	50	Y	Y	• Certification that liners were built have been submitted but was not available for case study • Presumably has 15 mil hypalon side liner with clay bottom liner • LCS is PVC drains to trenches around and under waste area • Leachate collected in sumps and either discharged for absorption at landfill area or trucked to treatment plant for diaposal • Amount of leachate generated not addressed in case study report • Groundwater has been contaminated • Chlorinated organic compounds have been detected (in soil?) • Leachate plume has been discovered , not sure if contamination is coming from this site or from adjacent closed sites

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

Attachment 3
(Cont.)

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
72	Rossman's	OR	1969	50	Y	Y	• No liner installed - natural 20 feet clay layer used as liner • Only surface leachate is collected • LCS relatively inaffective more leachate escapes than collected • Leachate is recirculated • Water balance calculations indicate that approximately 46 million gallons of leachate generated between December and April • GW contamination due to leachate has been detected and migrates beyond landfill boundaries
73	Lena Road	FL	1968	50	Y	Y	• No liner • In 1983 LCS consisted of ditches partially surrounding site. Ditchwater was pumped to pond/lagoon at corner of site • Slurry wall and storm water system built in 1985 • LCS is 8-inch O.D. perforated pipe • LCS expected complete in 1986 • Amount leachate generated not known, as LCS was not complete at time of case study • In 1983, GW contamination(metals and VOCs) was discovered • Contamination is from Lena Road and from adjacent closed site • Surficial aquifer also contaminated
74	Van Buren County[b]	AR	1985	50	Y	N	• Native silty clay used as liner • Not operated long enough to determine if leachate a problem • GWM results indicated high levels of COD, however, no GWM background data available for comparison
75	Brushy Island II[a]	AR	1979	50	Y	N	• No liner (20 feet of clay) • Based on monitoring results of April 1985, DPC&E concluded landfill was degrading the quality of local ground water (possibly due to pesticides) • Inconclusive information on leachate generation
76	Varnadore[a]	AR	1982	51	U	N	• Natural liner - 2 feet of suitable clay in excavated areas • No background data available to compare results of gwm - (one well only) • Insufficient information to determine if leachate is being generated or how much

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
77	Dumas[a]	AR	1974	52	U	N	• Shallow perched water encountered in site • No liner • No information on LCS • No GWM conducted • Not enough information in file to determine if leachate is generated or how much
78	Chattahochee[c]	FL	1982	55	Y	N	• Correspondence in file indicates that facility was closed but material still is being disposed of there • No liner • No LCS • Facility located in shallow GW area • Raw sewage and/or septic tank pumpings flowed from site into nearby creek in 1986 No record of extent of contamination, effects on human health or the environment, or type of corrective action taken • Leachate may degrade quality of nearby creek, which is a class III waterway • Amount of leachate generated not mentioned in case study • Accepts agricultural, commercial, residential wastes and sewage sludges, septic tank pumpings
79	Jackson East[a]	FL	1979	56	U	N	• Ordered by FDER in 1985 to close active site and operate only as transfer station • Natural liner from on-site clay. These clays, however, appear to exist as lenses and inconsistent beds • No LCS: Construction of LCS contingent upon detection of leachate • 1984 Operating Plan indicated that leachate had not developed • No environmental damage documented permit denied because facility failed to provide that site would not contaminate aquifer
80	Franklin County	FL	1980	56	Y	Y	• No liner • LCS is percolation trench. Trench is supposed to be connected to percolation pond but was improperly connected to stormwater discharge channel • Has failed to collect and treat leachate • Estimated 5.2 MGY of leachate generated • Final order in 1984 required facility to fill in connection between leachate control/percolation trench and storm water deversion ditch

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
81	Quinty Byrd[e]	FL	1975	56	Y	Y	• No longer permitted to accept significant quanities of hazardous waste • Bentonite polymer/soil liner used in wells #4 (bottom and final cover only), #6 and #7 (bottom, final cover, and sides) • LCS in cells 3,4,6,7 consists of lined trenches • Leachate collected in leachate treatment pond, then trucked to sanitary treatment plant or evaporated • Could generate 17.0 million gpy of leachate, first appearing in 6.5 years • No known, releases have occurred
82 86	Wright Sites I and II[a]	FL FL	1961 1978	60 60	U Y	U Y	• Prior to 1977, Site I operated as trash disposal dump • Both sites have filtration pond and surface impoundments • Leachate holding ponds lined with 34-mil CPSE • Surface water runoff also collected in leachate holding pond • Site II will have 40-mil HDPE liner covered with 18 inch of sand • LCS for Site II consists of network of underdrain and a barrier soil layer in the final cover • LCS for Site II will include grading cells/trenches so that water/leachate moves to one spot, where a pipe will be installed • Leachate from Site II will be pumped from sump trench into tank truck for disposal. Pumping schedule will vary as required • Site II employes leachate minimization features • Amount of leachate being generated not discussed in case study report • No environmental damage documented
83	South Dade	FL	1938	60	Y	Y	• Liner is planned for newer cells. Probably PVC, but may be hypalon or polyethylene • Current LCS: leachate collected in perimeter ditches, then sprayed back onto landfill • LCS will be PVC pipes in sand on top of bottom liner. Pipes will conduct leachate to pumping stations • At closure, leachate will be pumped to sanitary sewer • Amount of leachate generated not addressed in Case Study report • Numerous maintenance - related problems identified (apparently resolved satisfactory), including: - free flowing leachate observed on top of road - leachate seen overflowing perimeter ditches and entering swamp - VOC detected in leachate - Possible contamination of GW with lead

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
84	Central Disposal[c]	FL	1960s	60	Y	U	• Formerly buried wastes below groundwater level • Hospital wastes were illegally disposed of up until 1980 • Consists of 3 disposal areas: CDSLI, CDSLII, CDSLIII; CDSL I expected to close in 1986. Expansion area CDSLIII expected to open in 1986 • Oldest area has no liner. New areas will have 60 mil HDPE geomembrane bottom liners. Liners below LCS will be 120 mil • LCS for old area: leachate is induced by hydraulic gradient to travel through preoxidation ponds (leachate control canals) to mechanically aerated oxidation ponds, where it is retained and/or treated before recirculating into waste via spray irrigation. This system may no longer be operational • LCS for newer areas: perforated piping installed in soil layer on liner will carry leachate to collection sumps. Collected leachate will be trucked to waste treatment plant. Treatment method to be determined after completing studies on the leachate • Amount of leachate being generated not addressed in case study report • As early as 1981, GW had been contaminated by leachate
85	United Sanitation Services[a]	FL	1955	60	Y	Y	• Formerly placed waste in pits/trenches below GW level • Now has 18 inch compacted sandy muck/peat liner • LCS in use but not described in case study report. Perimeter ditches intercept percolated runoff leachate • Leachate production minimized • Amount of leachate generated not discussed in case study reort • Treatment method for collected leacnate not specificed in 1985 permit • GW contamination is possible • GW monitoring system is being expanded and waste being screened as preventative measures

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
87	Santa Rosa[a,e]	FL	1978	60	Y	N	• Sludges and septages formerly placed in unlined pond Stopped accepting them in 1985 • Probably accepted PCBs • Prior to 1985, cells were lined with 1 foot of silty, clayey, sandy soils from the site • 1985 permit required 24-inch clay liner but inspection revealed that this liner was not being installed • No LCS • In 1985, site reported generation of only insignificant quantities of leachate • No documented environmental damage, but potential future contamination is a major concern
88	Northwest 58th Street[c]	FL	1952	60	Y	N	• In process of final closure • Formerly buried waste below GW level • No liner before January 1985 • No LCS before January 1985 • Records do not confirm installation of liner or LCS • Amount of leachate generated not addressed in case study report • Leachate has significantly degraded GW quality No data on well sampling between 1975 and 1980. • Leachate plume identified and is traveling eastward • Consent final order issued after 1984 demanded excavation of percolation trenches to monitor/collect leachate
89	Broward County	FL	1964	60	Y	Y	• Bottom of sludge lagoon is unlined and at or below GW level. Estimated volume of sludge is 75,000 yd3 • New cell will have 40 mil HDPE liner placed on, and covered by, layers of sand • Existing cells have 1-inch asphalt liner over scarified and compacted soil, covered by 18 inch layer of crushed limestone • 30 mil HDPE liner and layers of crushed limestone and bentonite will be placed on existing cells to retard leachate migration • New cell will have underdrain to serve as LCS • Amount of leachate generated per month in 1985 varied from 0 to 654,000 gallons. Average quantify of leachate trucked to treatment plant for 11 months of available records was 370,000 gal/month

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

TABLE 1 MUNICIPAL SOLID WASTE LANDFILLS CASE STUDIES SUMMARIES (continued)

#	Facility Name	State	DFO	P	LI	LCS	Remarks
89	Broward County (continued)						• Leachate from cells is collected and trucked off-site to waste water treatment plant • Existing and potential GW contamination is believed to be mostly from industrial sludges in sludge lagoon as well as from the trash and MSW landfills • 1985 closure report recommended physical removal of sludge, stabilization with lime, and placement in active landfill cells. Files did not identify whether this procedure or an other is being implemented • Sludge deposition stopped in 1981, due to concerns about GW contamination
90	Perdido[a]	FL	1979	64	Y	Y	• Liner is minimum of 1 foot natural clay • Leachate controlled by trenches and underdrain • Leachate is pumped back into refuse, while clean water is diverted to retention ponds • Retention ponds are sediment control devices, but also serve to oxiding, and precipitate contaminants • Fate of 'clean' leachate water in retention ponds not addressed in case study report • Data indicates GW contaminating but reliability of monitoring wells is questionable. Facility has been instructed to abandon existing wells and install new ones
91	Tillamook County	OR	1949	100	Y	Y	• Originally no liner however liner requirements have changed over the years. Current liner is mixture of native soil and bentonite • GW and SW impacted due to leachate this resulted in lawsuit in 1985 • Lawsuit in 1985 required LCS to be upgraded and less permeable liner • 26 0 to 41 0 MGY of leachate generated

Reasons eliminated from evaluation:

a Insufficient data available
b Not operated long enough
c Waste placed in groundwater
d Operating procedures may have contributed to leachate generation
e Waste types received not identified
f LCS used to collect surface run-off in addition to leachate

Attachment 8
(Cont.)

TABLE 2. MUNICIPAL SOLID WASTE LANDFILLS - SUMMARY OF EVALUATION FOR PRECIPITATION CUT-OFF VALUE

Site	P	Leachate Generated	GW Cont. Due to Leachate
Landfill System, Inc., CO	15	Leachate generation seems minimal	—
Quail Canyon, TX	20	(no problems)	—
Tessman Road, TX	28	(no problems)	—
Marathon County, WI	30	1 MGY leachate collected 2.7 in/yr accumulated	—
Brown County, WI	30	2 MGY leachate collected 1.27 in/yr accumulated	—
Dane County, WI	30	0.25 MGY	—
Sunset Farms, TX	32	(no problems)	—
Sandtown (CSWF-1), DE	40	20 to 200 gpd (7280 GPY to 72,800 GPY)	—
Coffin Butte, OR	40	8.0 MGY	—
KFD/Reidel, OR	40	—	GW Cont.
Roseburg Central, OR	40	"Significant Problem"	GW Cont.
Grants Pass, OR	40	—	GW Cont. indicated (two memos from DEQ on pot. problems
Shelton, CT	41	—	GW Cont. Confirmed
Browns Island, OR	41	—	GW Cont. Well documented
Cherry Island, DE	42	30,000 gpd (10.9 MGY)	—
Wilton, CT	42	—	GW Cont. documented in 1976
Pidgeon Point ,DE	42	1.15 MGY	—
Canton, CT	43	—	GW Cont. (ordered closed in 1981)
Lichfield, CT	43	—	GW Cont. (ordered 50% of site closed)
Hartford, CT	44	—	GW impacted
South Windsor, CT	45	50,000 to 100,000 gpd (3.64 MGY)	GW Cont. (ordered closed in 1979)
Tolland, CT	45	—	GW Cont. (ordered closed in 1979)

TABLE 2. MUNICIPAL SOLID WASTE LANDFILLS - SUMMARY OF EVALUATION FOR PRECIPITATION CUT-OFF VALUE

Site	P	Leachate Generated	GW Cont. Due to Leachate
Carrol County, AR	45	—	(ordered closed due to leachate problems)
East Pasco County, FL	50	1.94 x 10^7 gpy (19.4 MGY)	—
Hillsboroug Heights, FL	50	—	GW Cont.
Rossman's, OR	50	46 Million gallons between December and April	GW Cont.
Lena Road, FL	50	—	GW Cont.
Franklin County, FL	56	5.2 MGY	—
South Dade, FL	60	—	Possible GW Cont. with leachate Problems
Broward County, FL	60	370,000 gal./month (4.4MGY)	—
Tillamook County, OR	100	26.0 to 41.0 MGY	GW Cont.

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To CALCULATION; To = D/K

Material	K Value (ft/yr)	To = D/K (years)				
		DEPTH IN FEET (D)				
		10	50	100	250	500
Sand	1.03E + 04	0.0010	0.0048	0.0097	0.0242	0.0484
Sandy Silt	1.04E + 02	0.0966	0.4831	0.9662	2.4155	4.8309
Silt	1.04E + 01	0.9662	4.8309	9.6618	24.1546*	48.3092
Silty Clay	1.04E + 00	9.6618	48.3092	96.6184	241.5459	483.0918
Clay	1.04E - 01	96.6184	483.0918	966.1836	2415.4589	4830.9179

Example: If To to Active Life ratio is 1:1, a 20 year landfill could locate in an area which has about 250 feet of silty overburden (* box) without a liner. If the ratio is 2:1, the same location would require a liner.

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Attachment 10

To CALCULATION; To = D/v = Dn/Ki

i = 1		To = D/V = Dn/Ki (years)				
		DEPTH IN FEET (D)				
MATERIAL	K VALUE (ft/yr)	10	50	100	250	500
Sand n = 0.25	1.03E + 04	0.0002	0.0012	0.0024	0.0060	0.0121
Sandy Silt n = 0.30	1.04E + 02	0.0290	0.1449	0.2899	0.7246	1.4493
Silt n = 0.35	1.04E + 01	0.3382	1.6908	3.3816	8.4541	16.9082
Silty Clay n = 0.40	1.04E + 00	3.8647	19.3237*	38.6473	96.6184	193.2367
Clay n = 0.45	1.04E-01	43.4783	217.3913	434.7826	1086.9565	2173.9130

Example: If To to Active Life ratio is 1:1, a 20 year landfill could locate in an area which has about 50 feet of silty-clay overburden (* box) without a liner. If the ratio is 2:1, the same location would require a liner.

Attachment 11

Examples of Leachate Collection System Requirements

Example 1

A hypothetical landfill, located in an area with 35 inches of annual precipitation, contains 5 feet of refuse at the end of the first year of operation. A water balance calculation (Fenn et al., 1975, EPA 530/SW-168) indicates that 11 inches of water is available to percolate through the refuse layer. The initial moisture content of the refuse is 15 percent, with a field capacity of 25 percent. Therefore, the amount of moisture required to bring the refuse layer to field capacity is 6 in. (60 in. refuse x (25-15%) = 6 in.). Each year, an additional 5 feet of refuse is placed above the previous layer (see Figure 1). To determine if a leachate collection system is required, a water balance is calculated for each year of operation. If a refuse layer has reached field capacity, the excess moisture is routed into the next layer below. This situation is summarized below:

1. Year 1 - Eleven inches of water percolate through the refuse; 6 inches is absorbed by the waste, which brings it to field capacity. Therefore, 5 inches of excess liquid reaches the bottom of the landfill.

2. Year 2 - An additional 5 feet of refuse is placed above the previous layer. As above, 5 inches of excess liquid is produced and is routed into the first layer. Since the first layer is at field capacity, the liquid percolates through the layer to the bottom of the landfill. Thus, the landfill has generated a total of 10 inches of leachate in two years.

3. Year 3 - An additional 5 foot layer of refuse is emplaced. Five inches of leachate are generated during the third year of operation as described above. This liquid percolates through the previous two layers to the bottom of the landfill, resulting in 15 inches of leachate generation over 3 years.

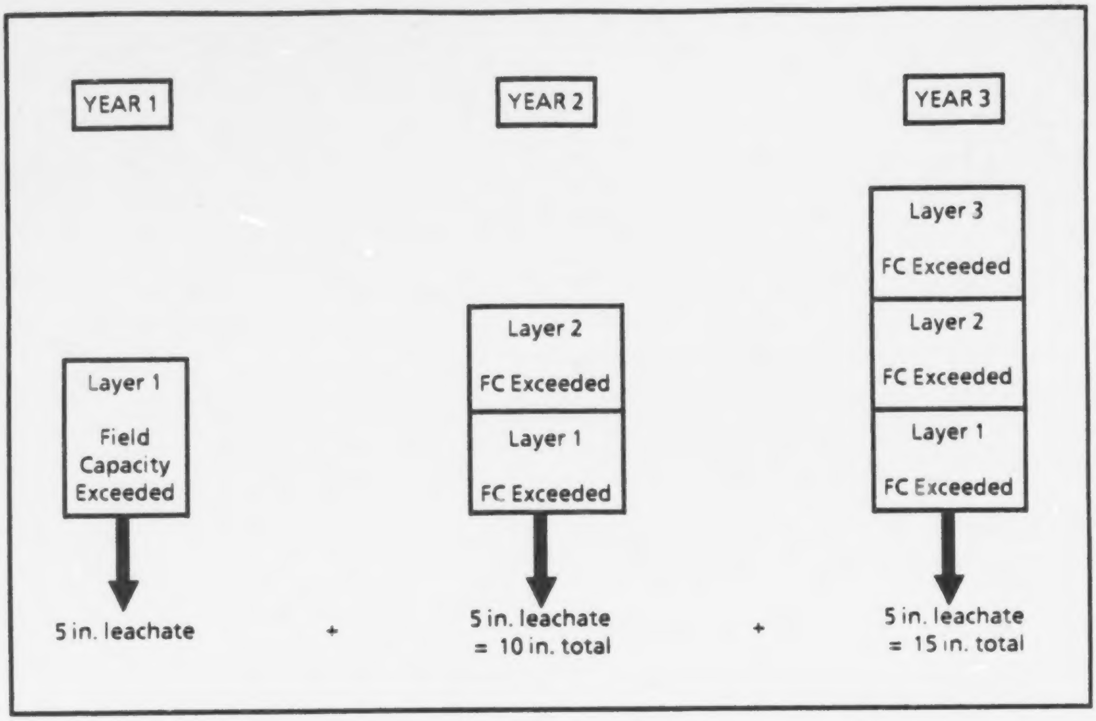
YEAR 1
YEAR 2
YEAR 3
Layer 3
FC Exceeded
Layer 2
FC Exceeded
Layer 2
FC Exceeded
Layer 1
Field Capacity Exceeded
Layer 1
FC Exceeded
Layer 1
FC Exceeded
5 in. leachate
+
5 in. leachate = 10 in. total
+
5 in. leachate = 15 in. total

Figure 1. Example of Leachate Generation for a Layered MSWLF Unit in a Wet Climate

4. Since more than 12 inches of leachate has been generated before this unit has been closed, a leachate collection system is required.

Example 2

An area landfill is constructed in the same climatic region as Example 1. Fifteen feet of refuse is placed in the landfill each year, and is capable of absorbing 18 inches of water at field capacity. Final cover is installed each year over the portion of the landfill that received wastes during the year (see Figure 2).

A water balance for this situation is sumarized below:

1. Year 1 - Eleven inches of precipitation infiltrates into portion one of the landfill. The refuse is capable of absorbing 18 in. of moisture; therefore, field capacity is not reached and no leachate is generated. Portion one is properly closed at the end of year one.

2. Year 2 - Eleven inches of precipitation infiltrates into portion two. Since portion one has been properly closed, this area is no longer considered in the water balance calculation. All infiltration is absorbed by portion two and no leachate is generated. Portion two is properly closed at the end of year 2.

3. Year 3 - Eleven inches of precipitation infiltrates into portion three. Since portions one and two have final cover, these two areas are assumed to not generate leachate. The refuse in portion three is capable of absorbing all infiltration and no leachate is generated. Portion three is closed at the end of year 3.

4. No leachate collection system is required in this situation since less than 12 inches of leachate is generated before each portion of the landfill is properly closed.

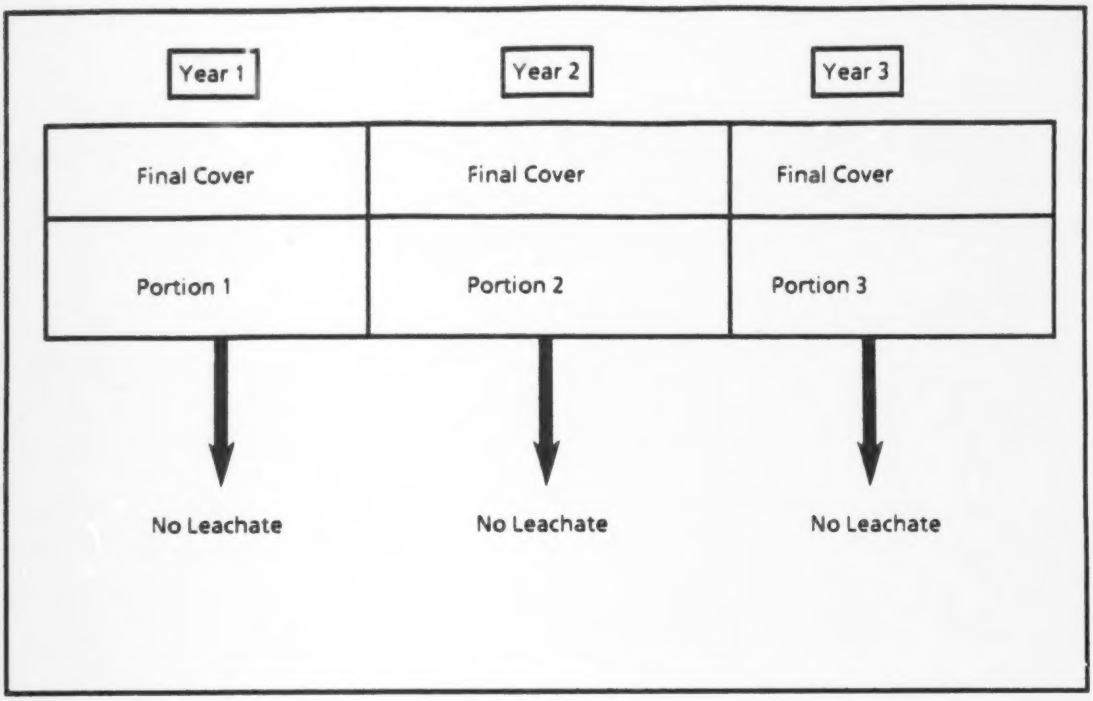
Year 1
Year 2
Year 3
Final Cover
Final Cover
Final Cover
Portion 1
Portion 2
Portion 3
No Leachate
No Leachate
No Leachate

Figure 2. Example of Leachate Generation for an Area MSWLF

Example 3

A layered landfill, located in an area with 15 inches of precipitation, is shown schematically in Figure 3. Five feet of refuse is placed in the landfill each year. An annual water balance calculation indicates that 2 inches of water will infiltrate into the refuse each year. Each 5 foot layer of refuse is capable of absorbing 6 in. of water to reach field capacity as described in Example 1. A water balance for this situation is summarized below:

1. Year 1 - Two inches of precipitation infiltrates into layer one of the unit. Since this layer can absorb 6 in. of liquid, field capacity is not reached and no leachate is generated.

2. Year 2 - An additional 5 feet of refuse is placed above the previous layer. Two inches of precipitation infiltrates into this layer during the year and is completely absorbed by the refuse. Field capacity is not reached, and no moisture is routed into the lower layer of refuse (i.e., no leachate is generated).

3. Year 3 - An additional 5 feet of refuse is placed above the previous layers. As described above, all infiltration is absorbed by this layer and no leachate is generated.

4. The unit is properly closed after 3 years of operation. Less than 12 in. of leachate is generated during this period; therefore, no leachate collection system is required.

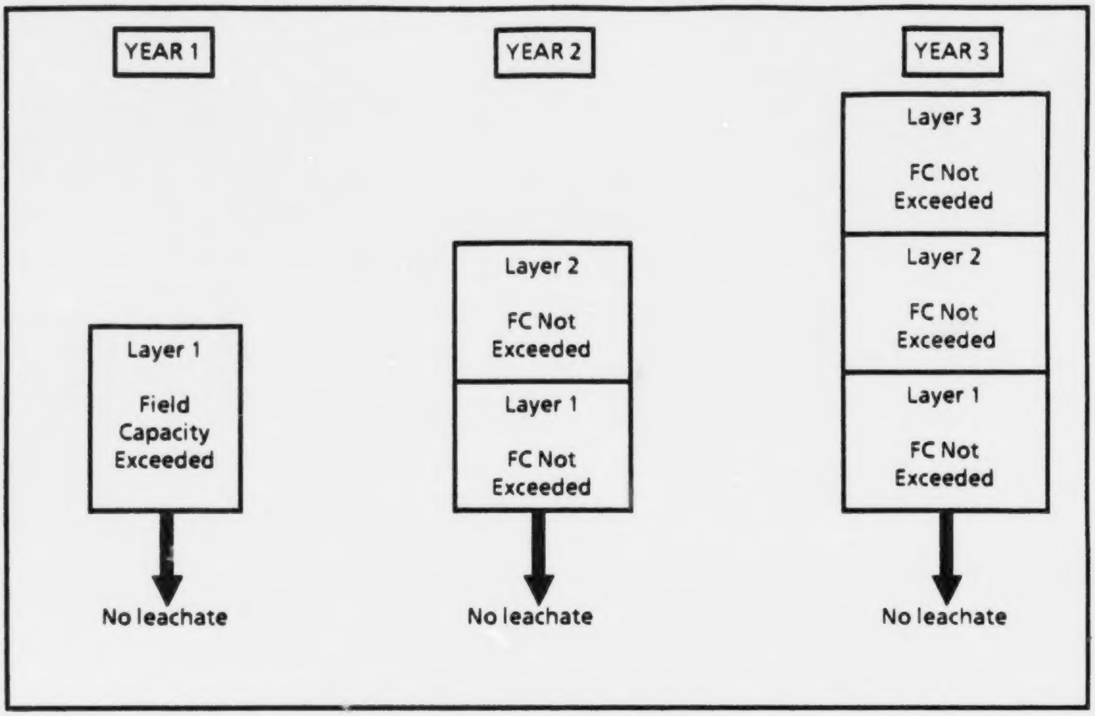
YEAR 1
YEAR 2
YEAR 3
Layer 3
FC Not Exceeded
Layer 2
FC Not Exceeded
Layer 1
Field Capacity Exceeded
Layer 2
FC Not Exceeded
Layer 1
FC Not Exceeded
Layer 1
FC Not Exceeded
No leachate
No leachate
No leachate

Figure 3. Example of Leachate Generation for a Layered MSWLF Unit in a Dry Climate

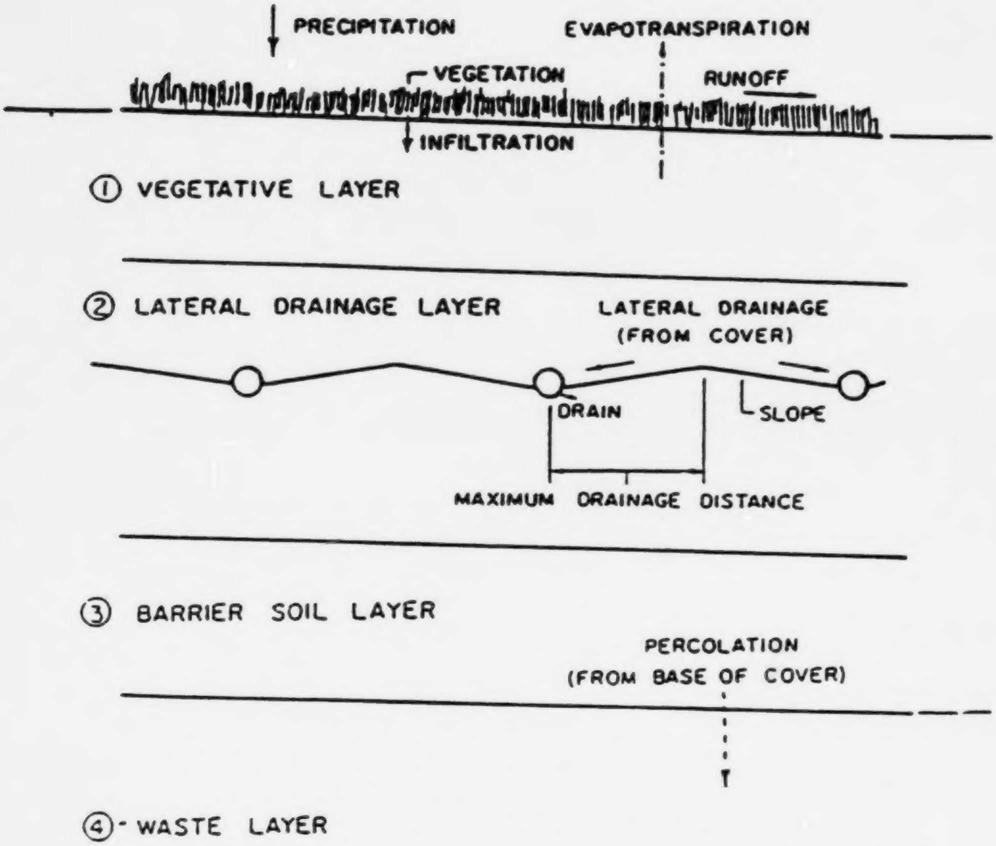
PRECIPITATION
EVAPOTRANSPIRATION
VEGETATION
RUNOFF
INFILTRATION
① VEGETATIVE LAYER
② LATERAL DRAINAGE LAYER
LATERAL DRAINAGE (FROM COVER)
DRAIN
SLOPE
MAXIMUM DRAINAGE DISTANCE
③ BARRIER SOIL LAYER
PERCOLATION (FROM BASE OF COVER)
④ WASTE LAYER

FIGURE 1. Typical Landfill Cover Profile
(Adapted from Schroeder et al, 1984a)